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THE

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AN HYPOTHESIS TO ACCOUNT FOR THE MOVEMENT IN THE CRUST OF THE EARTH.[1]

I WISH to propound an hypothesis to explain the vertical movements in the crust of the earth. As preliminary thereto I propose to set forth the most elementary phenomena of dynamic and structural geology in a summary manner so as to exhibit the nature of the facts requiring explanation.

The earth is composed of four bodies surrounded by the ether.

First, there is a central nucleus constituting the principal mass.

Second, there is a crust of structurally disposed rock surrounding the nucleus, the thickness of which is comparatively small.

Third, there is an aqueous body surrounding the rocky crust, through which the islands rise, the largest of which are called continents. On these islands there are many lakes and rivers which ramify into innumerable brooks, creeks and rills.

Fourth, there is an aërial mantle of air extending to a limit which is not well determined.

Fifth, these four bodies, one outside the other, in succession, are surrounded by the ether.

The earth is thus composed of encapsulated globes enclosing a nucleus and bathed in ether, to designate which certain defini-

[1] Read at the November meeting of the National Academy of Science, Boston, 1897.

tive terms are needed. I shall, therefore, speak of the nucleus, the rocky crust or crust, the aqueous envelope or envelope, and the aërial mantle or mantle, and shall call them all spheres. For the sake of clearer distinction, these spheres may be called (1) the centrosphere, (2) the lithosphere, (3) the hydrosphere, and (4) the atmosphere. It must be observed that the ether is common to all of the celestial bodies, and perhaps penetrates them as it does the earth.

The centrosphere is the chief mass and has a density of 5.6. By reason of this great specific gravity, which is about twice that of the rocky crust, it is often supposed to be metallic. Geologic facts in a vast system lead to the induction that the centrosphere does not exist in the solid state; if it is metallic the weight reduces it to a trans-solid condition. To this condition the form of the earth testifies, as it is an oblate spheroid assuming the figure of a fluid under the combined action of gravity and rotation. There are facts which have led physicists to conclude that it must have a rigidity said to be equal to that of steel. This rigidity may be explained as a function of its rotation, revolution, and molecular motion, when the physicist and geologist would be in substantial accord.

The theory of a metallic centrosphere seems adequately to account for the trans-solid state, as the metals are found to flow under pressure; but the molten material which from time to time is brought to the surface from the interior of the earth never reveals this metallic constitution. It may be that there is a zone of matter beneath the structural rock and overlying the metallic nucleus which is penetrated by heat, now here, now there, and only these molten rocks are extravasated; or it may be that the solid state is limited by heat in one direction and by pressure in the other in such manner that all rocks flow under great pressure as do the metals.

The stony crust has been revealed by direct penetration to a depth of more than six thousand feet, but it is indirectly revealed in many regions to a much greater depth, perhaps in extreme cases to fifty or sixty thousand feet.

The islands of dry land have all been beneath the sea at some time or other, and all show that they have been submerged more than once, some more frequently than others. During that portion of the history of the crust, which is the theater of geological investigation, these periods of submarine condition in one region always appear to be contemporaneous with periods of subaëreal conditions in some other region. Thus there seem to have been regions of dry land and regions of ocean bottom coexisting with a large predominance of oceanic area.

The aqueous envelope covers the rocky crust over about three-fourths of its surface, and has an average depth of about twelve thousand feet, though in extreme cases the bottom of the sea is more than five miles below its surface, while in some few cases mountains rise to more than five miles above the level of the sea. It is certain that we are now able to study rocks which were deposited at depths much greater than that of the mean depth of the ocean, and there are many cases where rocks found on the summits of high mountains are known to have been deposited at great depths beneath the sea. Great regions of country are at one time submarine, and at another subaërial. These oscillations of upheaval and subsidence are oft-repeated in geological history, and the swing of oscillation seems to have been in some regions tens or scores of thousands of feet where they reach the maximum, and to be only tens or scores of feet at the minimum, so that the surface of the earth, in so far as it has been studied geologically, is found to give evidence of oscillations of level varying in these quantities.

These variations are geographically heterogeneous, one region may have its oscillation on a small scale, another on a large scale, the minor oscillations forming distinct geographical series and the major oscillations forming distinct geographical series; that is, one region has been subject during geological time only to minor oscillations, and another during the same time to major oscillations.

We must now more fully consider the nature of these movements. Sometimes upheaval is by anticlinal flexure, where the rocks are lifted along a line of upheaval and caused to dip away on either side in gentle or abrupt slopes which are sometimes beautifully curved; but such an upheaval often seems to be accompanied by a subsidence on the flanks. Symmetrical anticlinal flexures are not very common, but often one side slopes gently while the other is abruptly deflected. This abrupt slope is especially subject to rupture, in which case faults are substituted for flexures. Thus a block which dips gently in one direction has its margin, on the side of a fault, displaced as an abrupt escarpment. Blocks formed in this manner often careen upon their edges, so that the strata may become vertically disposed or quite overturned where the lower formed strata are found on top. Between careened blocks and flexed blocks no line of demarcation can be drawn: the same block in different parts of its course may be bent or broken, and the flexed blocks themselves be quite overturned. The rocks which are upheaved or depressed by faulting and flexing, one or both, are always found to be ruptured in line of the faults or flexures, and also transversely to them. This rupture is often minute, so that the sheets of rock are faulted and jointed and thus found in blocks of varying dimensions, but all very minute as compared with the widely spread formations from which they are broken. Thus the whole system of rocks, of igneous and aqueous origin alike, are broken into blocks by faults and ruptures, and still further divided by planes of deposition, so that the structural crust is a system of fragments sometimes with an area of many yards, other times an area of fractions of inches. When we compare these blocks with the great area of the structural crust we find that it is but an accumulation of blocks that are to the formations what grains of sand are to the blocks. We must now realize that the structural crust nowhere has a continuous coherence; that faults, joints, and partings render it a vast body of minute and loosely accumulated fragments. All of this upheaval and subsidence with flexures, faults, joints, and partings seem to have been brought into this condition by intermittent convulsions often exhibited in earthquakes.

Having contemplated the lithosphere as a body moving in upheaval and subsidence, and shown what is about the maximum and minimum of these oscillations and their paroxysmal character, we are prepared to consider the structure of this crust.

In all geological ages volcanic eruptions have occurred and rocky material from the depths has been brought to the surface. Such appearances of lava at the surface have been very common in human history, and they appear to have been just as common in all the geological ages revealed by science. Lavas vary in chemical and mineralogical constitution, but this variation is within narrow limits. All of the mineral substances known to mankind appear, but are intimately mixed as minute ingredients. Lavas, therefore, are intimate mixtures of many substances, the average of which falls within narrow limits. It would appear from our present knowledge that the primordial surface of the earth was cooled lava and that lava has been erupted from time to time through all of the great geological ages.

Upon these cooled surfaces a new crust of rocks from below and rocks from above appears to have been spread. Wind waves and tidal waves are forever beating the lands and undermining the cliffs and distributing the materials beneath the sea. Then atmospheric agencies disintegrate the rocks and the rains wash the sands into the streams which carry them into the lakes and into the sea. By many cognate processes the lands are worn down and the sea bottoms built up; the amount of detritus thus accumulated in zones about the meandering shores is great, so that in regions of maximum activity formations are accumulated thousands of feet in thickness.

The winds contribute to the material which falls into the sea; plant life also furnishes its quota; accumulations of vegetation are ultimately consolidated among the formations as beds of coal; and animal life adds to the marine formations, for corals, shells, and bones are all brought to be buried in the sand, and often extensive formations of calcareous matter are thus produced. From these sources the sedimentary rocks are brought to be mingled with the eruptive rocks and intercalated among them, while in turn they are thrust between the sedimentary rocks.

Layers of rock of sedimentary origin appearing as strata are commingled with other masses of rock of volcanic origin which come from the interior. Sometimes the lava flows under or between the sedimentary strata. When great masses of lava are found in these conditions they are called lacolites. Thinner sheets are called intrusive rock. Beds poured over the surface are called coulées. The floods of lava come through fissures and fill them both below and above coulées, intrusions, and lacolites. Such fissure formations are called dikes; where the lava comes forth in volcanoes, the orifices are filled with molten rock which consolidates and are then called chimneys; great bodies of lava are ejected by some volcanoes as scoria and ashes, and often the ashes are minutely comminuted; the expulsion of such material is doubtless due to the production of gases and vapors, especially of steam, and the comminution is probably due to the explosive actions of particles of water expanded into steam. Great volcanic cones are often formed by the piles of scoria and ashes which are extravasated, and the ashes themselves when highly comminuted are drifted by the wind, sometimes far away from the locus of eruption. Beds of ashes and scoria formed in this manner are called tuff. So the bodies of rock formed by eruption are commingled with the bodies formed by sedimentation, and all are known as formations. Both the sedimentaries and the eruptives undergo a further change, which to a greater or less extent obscures their origin, for the original formations are metamorphosed, that is, recrystallized and lithified; so that the planes of sedimentation are partly or largely obscured and the beds of lacolites, intrusive sheets, coulées, dikes, chimneys, and tuffs have a new structure imposed upon them, and are then known as metamorphic rocks.

An attempt has been made to define formations; now they must be considered in a new light.

The land areas have always been subject to degradation by rains, rivers, and waves, and the materials washed from the land have been carried into the sea and there deposited; thus the continuance of dry land area is comparatively ephemeral. Not only are the lands degraded in this manner, but when they reach the level of the sea they continue to subside; when above the sea they are speedily unloaded, but when brought to the level of the sea or nearly so the islands, though having their loads discharged, continue to sink. The regions which have received the detritus of the islands and are thus loaded by them, are elevated into the island or continental condition; thus land areas rise to be unloaded and then sink, while oceanic areas are loaded and then rise to become land areas. The extent of this upheaval and subsidence and the vertical movements, involved together with the vast transportation of material from land to sea, seems to be enormous when we contemplate the almost silent and unseen agencies by which it is accomplished.

In considering large areas of the surface of the earth, as, for example, the great continents or zones of archipelagoes, we reach certain generalizations of prime significance.

Regions of great denudation are also regions of great deposition, regions of great eruption, regions of great upheaval and subsidence, and also regions of great flexure and fracture; thus denudation and deposition, eruption, displacement, as subsidence and upheaval and as fracture and flexure, are correlated in this manner: that where there is more of one there is more of all; where there is less of one there is less of all.

Geologists have found no law, condition, or cause by which to explain these phenomena of the earth's crust as the law of gravity explains the constitution of celestial systems. The search for this law has been almost exclusively in one direction, under the hypothesis of a cooling and contracting earth, but with the lapse of time it has been found inadequate. Attempts have been made to compute the amount of contraction supposed to result from the wrinkling of the crust of the earth in anticlines and synclines. It seems to entirely fail quantitatively.

Contraction does not seem to be an explanation of all or even the chief phenomena which we have briefly set forth. When this hypothesis was considered, flexion seemed to be the chief method of displacement; now we know that fracturing and faulting is the chief method in regions of maximum action. When inclined rocks are studied they seem to have been stretched, as evidenced in the elongation of particles transverse to the strike, and they seem further to have been stretched by the opening of fissures and joints. Altogether it may be affirmed that displacement does not teach the doctrine of a contracting earth, or, if that statement is too strong, it does not give evidence of a sufficient contraction necessary to the hypothesis, and it also fails to explain the concomitant phenomena.

With this hypothesis another is associated, namely, that the centrosphere of the earth is metallic, for which no vestige of inductive evidence has yet appeared; and the stupendous fact remains that the centrosphere has more than twice the density of the crust. All eruptive rocks which come into the purview of science are found to have an average constitution which is about the same as that of the sedimentary rocks. It is found by experiment in the industrial arts that under pressure metallic and other substances flow; and geology teaches that all of the other rocks are secularly deformed under differential pressures, so that rocks highly metamorphosed in this manner are twisted, contorted, and kneaded into new shapes. Finally, there is now abundant geologic evidence to show that the faulting near the surface appears as flexure at greater depths, and finally that flexure appears as molecular readjustment at still greater depths, expressed in slaty structure where the particles of the rocks are rearranged in parallel planes.

The metals of the normal condition have great density, but in a pure condition are found only in exceedingly minute quantities; all the other rocks have a small density. If now we assume that all rocks flow under pressure, that the critical point is variable and that the modulus of compression is also variable, being greater for the lighter rocks and less for the heavier, and that this modulus is greatly accelerated at the critical point, we have a law which will regiment the facts of geonomy as the facts of astronomy are marshaled by the law of gravity.

Under this theoretic law of the accelerated modulus of compression at the critical point for different substances, subsidence and upheaval are explained. The reassumption of constitutional structure in crystallization and glassy lithification necessitates expansion, and thus upheaval is explained. When lands rise and are denuded, the process of relithification in the centrosphere continues upheaval and exposes the lands to further upheaval, and this process goes on until an equilibrium is reached at the epoch when the land is brought to the level of the sea by degradation. On the other hand, as land is loaded the subjacent crust rocks are brought within the zone of accelerated compression, and this process continues while the loading continues until it is brought to a close at the epoch when the land area from which the detritus is taken is brought to the level of the sea and transportation ended so that loading ceases.

Universal contraction by cooling must still be postulated as an agency for the destruction of equilibrium, or perhaps we may find this agency in astronomical conditions ; but some such agency is necessary for the continuation of the process. But the changing of material from the interior to the surface and the changing of load from one district to another by transportation under the law of the accelerated modulus of compression is the principal agency of upheaval and subsidence.

This doctrine was proposed several years ago by myself, but has received little attention except among a few geologists engaged in this branch of research ; from its reception by these gentlemen I am encouraged to repropound it.

J. W. Powell.

ESTIMATES AND CAUSES OF CRUSTAL SHORTENING.[1]

INTRODUCTORY.

IN THE following paper I shall use the words crust and nucleus as terms by which to conveniently refer to the outer known solid shell of the earth, of which we have direct knowledge, and to the core surrounded by the crust, of which we have only inferred knowledge. The use of these terms in this sense is independent of any hypothesis as to a sharp boundary between the two, and of any theory as to the condition of the interior of the earth. So far as my present purposes are concerned, the nucleus may be entirely liquid, entirely solid, part liquid and part solid, or in a state of matter of which we have no knowledge.

The intricate phenomena of earth deformation, and particularly that form of deformation called folding, has led geologists to assume, in order to account for the facts in the field, that the surface of the earth must have been vastly shortened during geological time. Some instances of the estimates of the amount of crustal shortening may be mentioned.

Dutton[2] thinks, to explain the phenomena of folding since the close of the Cretaceous, that the radius of the earth must have been shortened more than thirty miles. He states that the plications are so great that we must assume a contraction on some circles of latitude since the commencement of the Permian amounting to many hundreds of miles, and this amount of contraction is small, he says, compared with that involved in the Laurentian rocks. Heim[3] estimates the transverse shortening of

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, p. 121.

[3] Mechanismus der Gebirgsbildung, von ALBERT HEIM: Basel, Band II, 1878, S. 213.

the Alps to be seventy-four miles. Le Conte[1] estimates the transverse shortening of the Coast Ranges of California to be from nine to twelve miles. Claypole[2] estimates the transverse shortening of the Appalachians in Pennsylvania to be forty-six miles. McConnell[3] thinks the folding of the Laramie range of British America required a transverse shortening of twenty-five miles.

In the above estimates of shortening by Heim, Claypole, Le Conte, and McConnell, I have inserted the word *transverse*, to call attention to the fact that shortening in only one direction has been considered by these authors. It is clear that to obtain an adequate idea of the effect of crustal corrugations, it is necessary to know in square miles the surficial lessening of the crust of the earth as a result of deformation. However, it appears that if in other mountain ranges the shortening is proportional to the estimates above given, the total amount of surficial decrease must be enormous. This would be true even if the deformation of ancient mountain ranges, the stumps of which are buried under later rocks, were ignored. Moreover, it is possible that the amount of folding and consequent shortening of the Paleozoic and older rocks, buried under the Mesozoic and Cenozoic strata, may be as great or even greater than the amount of shortening involved in the deformation observable at the surface.

The theory of mountain-making as a result of secular cooling has been repeatedly attacked along the lines of the vast contraction demanded by the supposed facts of the field, and the small contraction resulting from secular cooling, the only cause ordinarily assigned for contraction. Dutton[4] calculates that the

[1] On the structure and origin of mountains, with special reference to recent objections to the contractional theory, by JOSEPH LE CONTE: Am. Journ. Sci., Vol. XVI, 1878, p. 98.

[2] Pennsylvania before and after the elevation of the Appalachian mountains, by E. W. CLAYPOLE: Brit. Assoc. Rept., Montreal meeting, 1884, p. 718.

[3] Geological features of a portion of the Rocky mountains, by R. G. McCONNELL: Geol. Surv. of Can., Ann. Rept., Vol. II, Pt. D, 1886, p. 31.

[4] Loc. cit., p. 120.

contraction due to secular cooling is mainly confined to the outer 200 or 300 miles of the earth, and states: "Although no estimate can be made of the contraction of this portion, it is probably safe to say that its volume cannot have been diminished so much as one-tenth; and if we were to assign thirty miles as the diminution of the earth's radius since the formation of a cooled exterior, we should probably reach the utmost limits consistent with Fourier's theorem."

It is believed, upon the one hand, that there may have been great overestimates of the amount of crustal shortening, and upon the other hand, that important causes for nucleal contraction may exist which have not been sufficiently considered. It is the purpose of this paper (1) to examine the evidence upon which estimates of crustal shortening have been made, and to consider the methods to be followed in making estimates of shortening, and (2) to summarize the known causes which may exist for nucleal contraction and crustal corrugation. The paper may thus be divided into two parts. In Part I, I shall consider the shortening of the outer surface of the earth accompanying folding, faulting, jointing, cleavage, fissility, and vulcanism and cementation; and in Part II, I shall consider the causes which may account for the shortening represented by the phenomena.

PART I. ESTIMATES OF CRUSTAL SHORTENING.

Folding.—The deformation of folding undoubtedly involves shortening, but it is believed that it does not necessarily require nearly so much shortening as has been believed. Estimates of shortening resulting from folding have not considered the effects of the following phenomena: (1) the thinning of the layers produced by folding; (2) the composite character of folds and the rapid variations in the closeness of the folds of the various orders; and (3) the effect of gliding on the limbs of folds.

1. In order to make an estimate of the amount of shortening involved in folding, it is necessary to recall the nature of the deformation of the individual beds and formations. It has been

shown[1] in another place that the mashing, flowage, and the shearing motion involved in differential movement between the layers necessarily involves thinning of the limbs of the folds or thickening of the troughs and crests, or both. Even where the

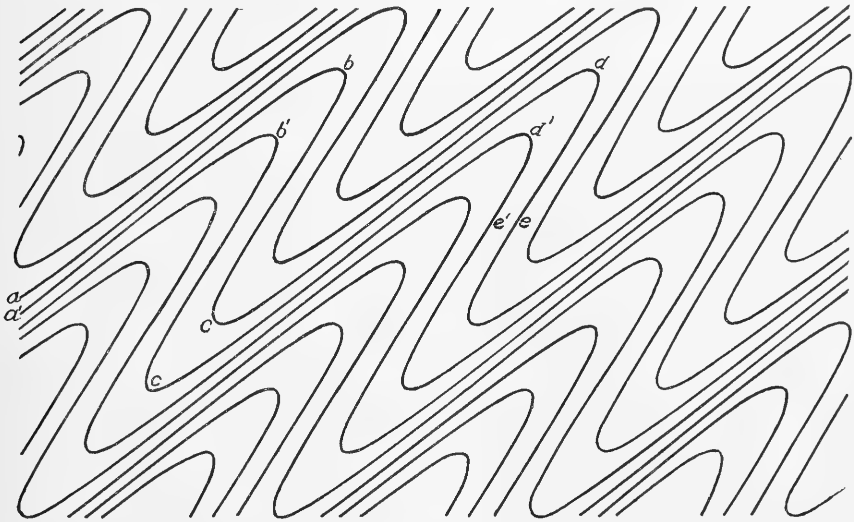


FIG. 1.—Similar monoclinal folds.

folds are not close, in case the folds are similar,[2] the limbs may not be much more than half as thick as are the troughs and crests (Fig. 4). This distortion becomes more and more important as the folding becomes closer, and in isoclinal and monoclinal folds, in which the strata turn back upon themselves, the amount of thinning of the limbs or thickening of the troughs and crests is very great (Fig. 1). A layer when traced out in such a set of folds alternately thins and thickens, and the section if developed on a plane, would alternately greatly widen and narrow (Fig. 2). The length of the developed layer should be the length of its central part. The excess of material for each

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 599.

[2] Loc. cit., pp. 599–600.

curve on the convex side of such a central line would equal the deficiency on the concave side, and consequently such a developed layer truly represents its mass and average length. If it be assumed that the original horizontal stratum had a

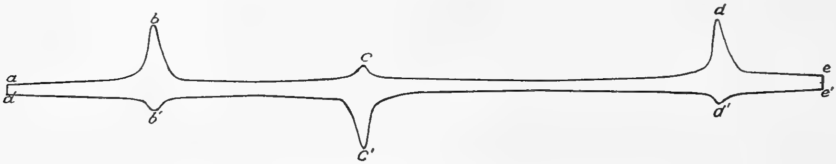


FIG. 2.— Development of a part of a layer of Fig. 1.

thickness equal to the thicker parts of the folded stratum, it would follow that the developed stratum is much longer than it was originally. However, probably in no case is this assumption wholly correct, and in many cases it is far from the truth. The weaker and stronger layers require consideration separately.

At most places the evidence seems to show that during deformation the anticlines and synclines of the weaker layers have been thickened. However, since during the deformation there is shearing motion under pressure all along the limbs, it can hardly be doubted that in many cases the thinning of the layers is a more important phenomenon so far as their length is concerned, than thickening on the anticlines and synclines.

In the stronger layers, often no evidence of thickening is anywhere seen. Upon the contrary in many cases, as will be shown below, the layers are actually elongated by tensile fracture upon their convex sides and therefore cannot have been thickened. Radial open fractures upon anticlines and synclines, due to tension, are beautifully exhibited in the southern Appalachians (Fig. 8). The openings in many cases have been filled with quartz. These joints are evidences of tensile forces. Where stretching of anticlines and synclines occurs in the zone of flowage, this is undoubtedly due to the great friction between the layers, and to their positions on the convex sides of the neutral planes. The limbs of the stronger layers, like those of the weaker beds, are subjected to differential shearing under pressure, and if distortion occurs they must be thereby thinned.

The actual thinning and elongation of layers as a result of folding has been noted by Le Conte[1] as an important phenomenon in the Coast Ranges of California, and by Reade[2] in various mountain ranges.

According to Gilbert,[3] during the introduction of igneous rocks, which formed the Henry mountains, the pressure of the magma normal to the strata was so great that they were extended laterally by flowage a sufficient amount to cover the domes. In the case of the Holme's arch the linear extension was about 2 per cent.

The amount of thickening or thinning, which any given formation or layer undergoes, will of course depend upon many factors, among which attitude, strength, pressure, amount of differential movement or shearing are to be considered.

As noted by Reade,[4] the attitude of the layers is of the greatest importance. In their initial position the tendency of the pressure is to thicken them. This tendency continues as the layers are tilted, until the average dip is 45°. As soon as the layers upon the average have a greater inclination than 45° (Fig. 1), the average effect of the tangential pressure is unquestionably to thin the layers, although some members at certain places, and especially at the turns, may be thickened. When it is remembered that in the closely-folded mountains the layers generally have dips greater than 45°, and as explained later (pp. 16–17) such layers usually turn quickly at the anticlines and synclines, it becomes evident that the thinning of the layers and their consequent elongation, as a result of tangential pres-

[1] On the structure and origin of mountains, with special reference to recent objections to the contractional theory, by JOSEPH LE CONTE: Am. Journ. Sci., Vol. XVI, 1878, pp. 299, 301, 302.

[2] The origin of mountain ranges, by T. MELLARD READE: London, 1886, pp. 176, 208, 211.

[3] Geology of the Henry mountains, by G. K. GILBERT: Rept. U. S. Geog. and Geol. Surv. of the Rocky mountain region, 1877, pp. 80–82.

[4] Loc. cit., pp. 216–217.

sure in positions which average greater than 45°, may be very important. In reference to the other factors, the greater the pressure, the greater the tendency for thickening and shortening at angles less than 45°, and the greater the tendency for thinning

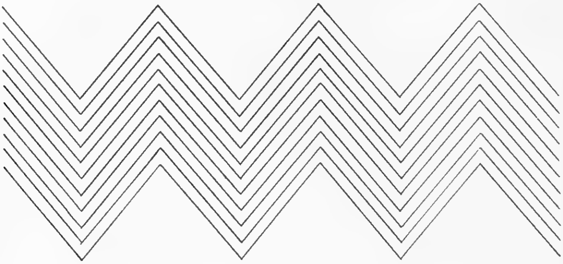


Fig. 3.—Similar upright folds with angular crests and troughs.

and lengthening at angles greater than 45°. The greater the shearing between the layers, the greater the thinning. The greater the rigidity of any given layer, the less the thinning.

The foregoing statements are understood to apply to strata which are so deeply buried that the deformation of the layers results from true interior distortion of them. In the upper zone of fracture these statements need to be modified, as subsequently explained.

With present data only these qualitative statements can be made. But, it seems probable that in the earlier stages of the development of folds, the average thrust thickens instead of thins the layers. However, where the folds are very close, and especially in isoclinal and overturned folds, it can hardly be doubted that upon the average there is considerable thinning and consequent important elongation of the layers. For folds of a given average closeness the average amount of distortion is not so great where the strata bend back upon themselves with sudden turns, as where the bends occur gradually (compare Figs. 3 and 4), although the distortion at the angles may be greater than at the corresponding places upon the gentle turns. In nature the deformation is ordinarily between the two extremes figured.

The fact that the distortion is less in folds with sudden turns than in those with rounded turns, is believed to be a cause why this deformation so frequently occurs in closely-folded rocks. The angular deformation requires less work, and there-

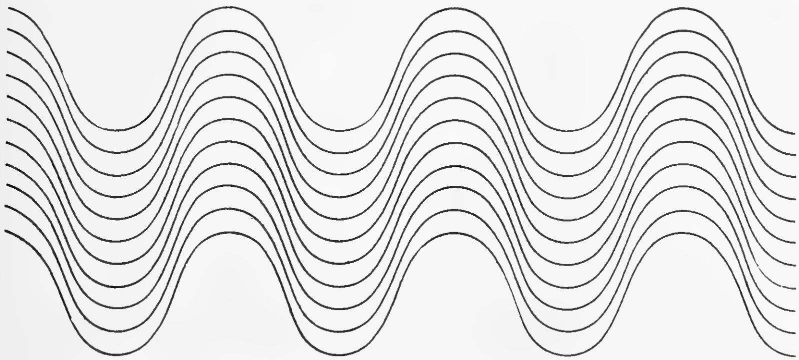


FIG. 4.— Similar upright folds with rounded crests and troughs.

fore less energy than the other form. As the stresses slowly accumulate until the elastic limits of the rocks are surpassed, the deformation which will occur in any given case in order to relieve the stresses is that which requires the least expenditure of energy under the existing conditions. This is the old principle that a mass under stress gives way along the lines of least resistance.

2. In estimating the amount of superficial shortening involved in folding, it is necessary to consider what and where strata shall be selected for estimation. I have shown that if there is no thinning or thickening of the layers (Fig. 5) folds rapidly die out above and below any given folded layer. I have also shown that similar folds are only possible by profound distortion of the layers (Figs. 1 and 4), unless the turns are very abrupt. Agreeing with theory, actual geological sections are a compromise between parallel folds and similar folds, the folds rapidly varying in closeness in different parts of a mountain mass, vertically and laterally.[1]

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 599–601.

In this connection it should be remembered, if the theory of a level of no lateral stress be true, that a good reason exists for the lessening folding and distortion of layers with increasing depth.

Whether or not this theory as ordinarily stated approximates

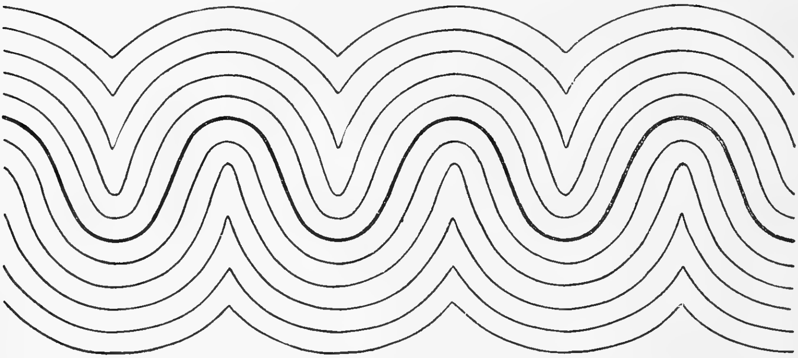


Fig. 5.— Parallel upright folds with rounded crests and troughs.

quantitative correctness, it is certain that the amount ot shortening must somewhere decrease with increase of depth; for infinitesimally near the center of the earth the amount of shortening must be infinitesimally small. Since with present knowledge we can only conjecture the law under which folds die out in depth, though we are certain that they must die out, one is not justified in assuming that folds similar to those at the surface continue even for moderate depths.

If this principle be ignored in estimating shortening, a serious error may be made. The formation being followed may plunge beneath softer formations which show close plications. If it be assumed that similar plications also effect the formation below to be measured, this may lead to a considerable overestimate of the amount of crustal shortening (Fig. 6).

Also the lateral variation in closeness of folding may lead to error. If the layer or formation to be measured is not continuously exposed, it may be visible where it chances to be most closely folded and be concealed where more openly folded. If at the places of less folding the strata chance to be hidden, the plications of other strata must be selected to fill in the gap. Layers may be selected which exhibit close folding. But even if layers are selected which show the least folding of any in sight,

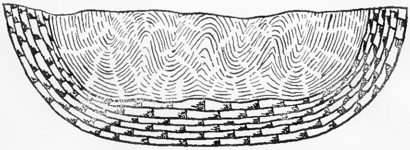


FIG. 6.—Simple fold below composite folds.

there is still a possibility that a considerable overestimate may be made of the closeness of folding and of the amount of crustal shortening.

For oftentimes, where a formation upon which estimates of shortening are being made, disappears below the surface, this results from its plunging downward as a part of a synclinorium. It is believed that upon the average synclinoria are less closely folded than anticlinoria. Anticlinoria are places of crustal thickening resultant upon close plications, whereas synclinoria are areas ot depression as compared with the anticlinoria, but not really areas of depression as compared with the unfolded districts. If the plications of synclinoria were as composite as anticlinoria, this would involve an equivalent amount of thickening of the crust, and consequently equal elevation with the anticlinoria unless a large amount of material, to compensate for the difference in elevation, had flowed from below the synclinornia to below the anticlinoria. Doubtless the flowage of the kind suggested does take place to some extent, but to no such extent as would be involved in this hypothesis

Willis's experiments most beautifully illustrate the composite character of the folding of anticlinoria as compared with the intervening synclinoria.[1] The above reasoning applies exactly

[1] The mechanics of Appalachian structure, by BAILEY WILLIS: 13th Ann. Rept., U. S. Geol. Survey, Pt. II, 1893, Pls. LXXVII, LXXXI, LXXXII, LXXXIV, LXXXV, LXXXVI.

to his experiments. When the strata were compressed in these experiments there was flowage from below the synclinoria, but not a sufficient amount to allow the synclinoria to become as plicated as the anticlinoria, and at the same time to be at a lower level.

3. In anticlinal mountain masses the cores, composed of the oldest and originally deepest-buried strata, are often less closely plicated than the strata on the flanks of the mountains, which are composed of younger rocks. In estimating the crustal shortening of such mountain masses, we have, therefore, the

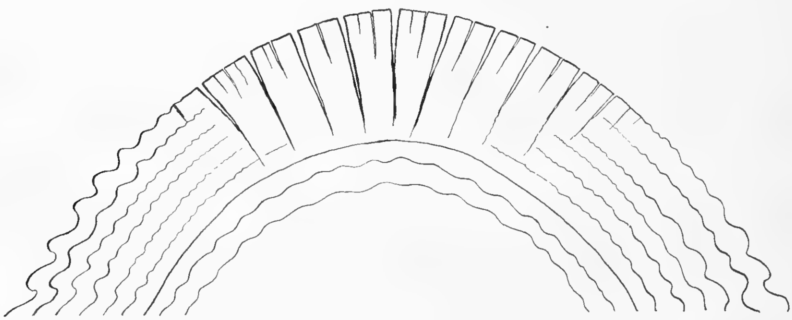


FIG. 7.— Possible relation of secondary folds to joints.

difficulty already mentioned, that is, folds of different layers vary in their closeness. This occurs notwithstanding the fact that upon the limbs one would expect that differential movement between the layers, or shearing, which tends to stretch them rather than to produce plications, are at a maximum. The greater folding of the limbs, as compared with the cores may be partly explained by the principle already given, that in general folds die out as depth increases, and consequently the older strata are least folded. However, the plications are probably to be chiefly explained by the gliding of the material down the slope upon the flanks of the mountain, because under the stress of gravity (Fig. 7). The strata on the crests may have been removed by erosion, or, as explained in another place (see p. 24), the stresses may have there produced joints. In either case the material on the flanks is no longer held in position by the tensile strength of the rocks on the crest, and under the stress of gravity slides down the slope, and this results in corrugations. The plications upon the flanks may thus be partly or fully compensated by separation of the material along the crests. However, the plications may be inferred, in estimating crustal shortening, to have extended to the part removed by erosion. In this case the amount of crustal shortening due to folding would be overestimated. In reality, the original length of the strata was that of a gentle continuous curve of the order of magnitude of the mountain mass.

The question may be asked as to the reality of the existence of the gliding effect above assumed as a result of the action of gravity. In another place[1] I have fully discussed the forms of the secondary folds which occur in composite anticlinoria and synclinoria of the first order. It there appears that the secondary folds upon the flanks of the mountains so commonly have attitudes which must have resulted from this gliding effect, that the composite folds, the secondary folds of which show such attitudes, have been called normal composite folds. This discussion cannot be here repeated, but if the argument given be correct, the gliding effect due to gravity producing secondary corrugations upon mountain flanks is a significant phenomenon, and consequently the cause here assigned for overestimates of the amount of crustal shortening is of importance.

It is clear that in appealing to the force of gravity to pro duce corrugations upon the slopes of the mountains, I am follow ing Dana[2] and Reyer.[3] However, I do not follow the latter fully. He makes the gliding the cause of the formation of mountains, whereas, it is clearly an effect, following the mountain-making. Material cannot glide down until it has been raised up. My

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 608–615.

[2] Geological results of the earth's contraction in consequence of cooling, by JAMES D. DANA: Am. Journ. Sci., Vol. III, 1847, p. 185.

[3] Theoretische Geologie, by E. REYER: Stuttgart, 1888, p. 829.

present point is that if the corrugated parts are alone considered, and the jointed part or the part removed by erosion ignored, that the average crustal shortening may be greatly overestimated.

If the considerations presented in the foregoing pages have weight, it is clear that the actual measurements in the field of the amount of crustal shortening involved in folding presents great difficulties, and the question naturally arises as to the best practicable methods of procedure.

1. So far as practicable, the same formation should be measured throughout a section, and if it is necessary to transfer from one formation to another, the greatest care should be exercised in order to avoid the errors which may result from changing from a formation to another lower or higher, and also to avoid the error which may come in as a result of the lateral change in closeness of plication.

2. The strongest formations available should be selected for measurement.

This selection should be made because the stronger formations have less composite curves than the weak ones. As a consequence they are less distorted during the folding than the weak formations. These facts may be observed in almost any good section of closely-folded heterogeneous strata. The more composite crenulation, but not the greater thinning and thickening, of the weaker layers may be illustrated by bending a rectangular pile composed of bunches of paper alternating with cardboards, the pile being held firmly either mechanically or with the fingers at the edges, so that slipping between the laminæ may be hindered at the places held. In this experiment, at the crest or trough, spaces form between the stronger layers, and in these spaces the weaker layers take on secondary crenulations. In natural geological sections the pressure upon the limbs is frequently sufficiently great so that the material of the weaker layers flows toward the openings on the anticlines or synclines, and partly or wholly occupies them. In many places some of the weaker layers are quite pinched out upon the limbs.

The physical cause for the simple folding of strong layers and the composite folding of the weaker layers is that already assigned for another kind of deformation on p. 17, namely, under given conditions, the deformation occurs which demands the least expenditure of energy. To deform the strong layers in a composite way requires a large amount of energy. To deform the weak layers in a composite way requires much less energy. The simple deformation of the strong layers and the composite deformation of the weak layers demands less energy than would be required to deform all the layers in a similar manner, so that the deformation would average the same as in the case of the unequal deformation of the strong and weak layers.

Under different circumstances the strong layers vary greatly in the simplicity of their deformation. In case the load is not too great, as explained by Willis, the strong layers are bent into large, simple folds. If, upon the other hand, the load is too great for the strata to support, the strong layers are folded in a composite manner. Both of these cases fall under the principle that the deformation occurs which requires a minimum expenditure of energy, for in the case of the lighter load, it requires less energy to elevate the load on the anticline, or to somewhat depress it on the syncline, than it does to greatly distort the strong formations. But in the case of the great load it requires less expenditure of energy to distort the strong layer a sufficient amount to make it develop composite folds than it does to elevate the load. But as above stated, even in the case of composite folding of the stronger layers, the weaker layers adjacent to them show still more composite deformation.

The statement made that the strong formations should be selected for tracing above the surface and for measurement is therefore justified.

3. From the places where the strong formations plunge below the surface to the places where they reappear, only the most gentle curves should be assumed (Fig. 6).

4. From the places where the formation which is being measured is lost because removed by erosion, only the most

gentle practicable curves should be assumed to the places where the formation reappears, and even if this be done, as shown (pp. 20–22) an overestimate may be made of the length of the formation.

5. It should be ascertained whether the formation measured has upon the average been thinned or thickened, and a corresponding allowance should be made.

If the principles are not appreciated upon which the foregoing precautions are based, with the natural, indeed almost inevitable tendency for one to pick out strata for measurement which have suffered severest deformation here, and severest deformation there, we may be sure that estimates of shortening will have comparative little value.

Jointing.—In another place[1] I have explained that joints may be of two kinds, tension joints and compression joints. Tension joints in simple folds may form in one direction at right angles to the bedding, or nearly so, in the zone of fracture (Fig. 8). In the case of complex folding, two sets of tensile joints intersecting each other at right angles may develop, both, however, still normal to the bedding or nearly so. Compression joints, forming in shearing planes, are ordinarily more or less diagonal to bedding. However, the greatest compressive stresses may approximate angles of 45° to the bedding, in which case the shearing fractures would be nearly normal to bedding. Compression joints, like tension joints, may develop in two directions at right angles to each other.

In the gentle folds of the Paleozoic of the Mississippi valley and the strata of the plateau country of the far West, joints are normal to the bedding, or nearly so, corresponding in position to the direction of the folding. For instance, southern Wisconsin is a gentle southward-plunging anticline, in other words, the principal fold has a nearly north-south axis, and the rocks dip east to Lake Michigan and west to the Mississippi river. Corresponding to this arrangement are numerous joints in a north-south direc-

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 668–672.

tion. However, the plunge of this anticline varies in passing from north to south. In other words, there is here a great but very gentle cross fold, and corresponding to this is another set of joints which run in an east-west direction.

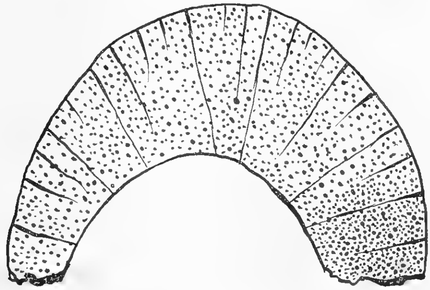


FIG. 8.—Tensile joints.

The same arrangement of joints is still better illustrated in the closely folded Allegheny mountains, and the Coast Ranges of Oregon and California. In the Allegheny mountains, as may be seen by sections along the railroads (for instance, the Pennsylvania, and Baltimore and Ohio) in the stronger beds there are two sets of joints everywhere corresponding to the strike and dip, in other words, corresponding to the two directions of fracture due to longitudinal and transverse folding.

Such joints may be seen both in anticlines and synclines. They occur in sandstone, grit, or limestone. Where the layers are a foot or more in thickness, and the rocks are gently folded, the joints may be several feet apart. Where the layers are closely folded the joints are frequently less than a foot apart. In the thinner layers, those from two to six inches in thickness, the joints are ordinarily less than a foot apart, and where closely folded are but two or three inches apart. Indeed, in some cases of close folding, the two sets of joints are so close together as to break the formations into a set of parallelopiped blocks, the dimension along the bedding being the least of the three, that is, the joints are closer together than the thickness of the beds.

It is apparent that the Paleozoic strata of the Mississippi valley and of the Plateau region, the Alleghenies, and Coast Ranges were folded under such conditions that the curves of the folds were produced not by actual bending of the layers, but

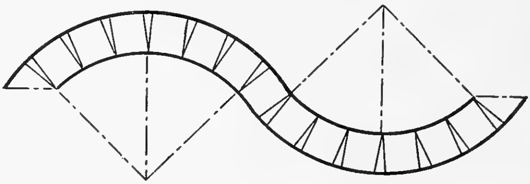


FIG. 9.—Diagram of radial openings produced by tensile fracture.

by numerous fractures, with a slight displacement of each block, resulting in a curved form (Figs. 9 and 10).

Now these joints must have been produced by tensile stresses or by shearing stresses. If they are of the first class, it is self-evident that the production of the joints involved surficial elongation (Fig. 9). If they are of the second class, their production may have involved all of the surficial elongation (Fig. 10), and it will be explained in a subsequent number of this JOURNAL[1] that joints of this kind are believed to be widespread. Some reasons for this belief may here be mentioned. These joints in many regions show a marked tendency to a vertical attitude, as in figure 10. Also the kind of displacements generalized in figure 10 has been observed at various places. Moreover, such joints are closer together the closer the folding, and in some cases they are so close as to make the intervening masses approach leaflets, as, for instance, in sandstones and shales on the Chesapeake and Ohio canal, three miles west of Hancock, Md.

In both the cases of joints produced by tension and shearing above described, there is no real elongation of the strata, but merely a displacement of the blocks causing surficial elongation. In the case of the tension joints this elongation is due to the fact that spaces are measured; in the case of the

[1] Deformation of rocks, by C. R. VAN HISE: JOURN. GEOL., Vol. VI, 1898.

shearing joints the apparent elongation is due to the fact that the measurements are diagonally across the blocks, instead of following the bedding.

From figure 9 it is plain that the average theoretical elongating effect of tension joints is directly as the thickness of the layers or formations through which the joints continuously extend, and indirectly as the radius of curvature. In the field it oftens happens that as a result of the position of a layer or formation upon the convex side of the neutral plane of deformation, the different blocks are separated from one another on the concave sides of the curves as well as on the convex sides.

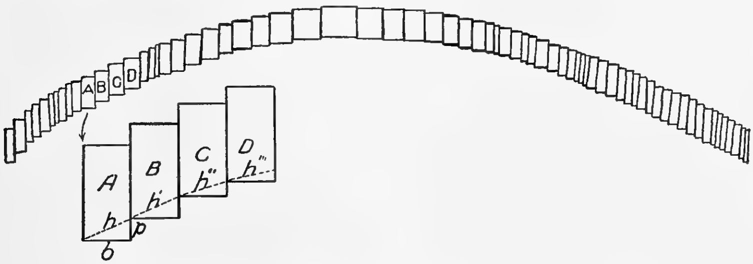


FIG. 10.—Surficial elongation resulting from shearing joints.

From figure 10 it is plain that the surficial elongating effect of the shearing joints is great in proportion to the displacements along the joints, and to their frequency. The apparent length in any case is the sum of the hypotenuses of the right angle triangles ($h + h' + h'' + h'''$, etc., Fig. 10), the bases of which are the lengths of the blocks parallel to the bedding, and the perpendiculars of which are the displacements.

It is not to be concluded from these illustrations that there is no crustal shortening as a result of joint folding. Shortening might occur even if the entire bending were accomplished by tensile joint fracturing. Also in the case of the shearing joint fracturing the rubbing of the blocks against one another might produce shortening.

However, if an estimate of the original surface of the layers were made, upon the supposition that it was as great as it would appear to be if developed on a plane, this would result in a considerable overestimate of the amount of its original surface.

In many of the weaker layers of folded rocks is a diagonal jointing, due to differential motion, and cutting this diagonal jointing nearly at right angles is a diagonal fissility.[1] The whole may result in thinning the limbs of the folds, just as does the shearing motion in the case of folding by plastic flow.

It is very desirable that the quantitative value of the lengthening effect of jointing should be known for various kinds of deformation. This, however, is an exceedingly difficult task. The quantitative value of the surficial elongation due to jointing for any deformation of an area can be only approximately determined after an extensive and close field study of the district. Consequently, for the present, I am obliged to be content with comparative statements which rest upon my own judgment, and which may be questioned by other observers. I believe the elongating effect of jointing to be quantitatively of sufficient importance that it should be taken into account in estimates of crustal shortening. I believe the lengthening effects of joints are important in connection with the estimates of shortening due to folding where the folds on the flanks of mountains may be due to a downward gliding effect, and be compensated by the joints (see Fig. 7), as explained on pages 20–22. However, I suppose that the elongating effect of jointing is not so great as that of the distortion of closely folded rocks in the zone of flow, as explained on page 16.

Faults.—Faults are ordinarily classified into normal faults and reverse faults. The normal faults involve an elongation of the crust of the earth as certainly as the reverse faults involve a shortening of the crust of the earth.[3] The very names, normal and reverse faults, show that the first are of far greater abundance,—are in fact the rule.

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 651–654.

[2] Supplementary notes on deformation of rocks, by C. R. VAN HISE: JOURN. GEOL., Vol. V, 1897, pp. 190–191.

[3] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 674.

However, since the hade of a reverse fault is usually flatter than that of a normal fault, the shortening due to a given vertical displacement of a reverse fault exceeds the shortening due to the same displacement of a normal fault. In considering the elongation or shortening of the crust of the earth by faults, this factor must be considered, as well as the factor of their relative frequency and area of distribution. However, reverse faults are usually confined to closely-folded areas, while normal faults frequently occur in these same areas, developing in the final stages of deformation, and are also present throughout great regions where reverse faults are absent, as, for instance, in the Great Basin and Plateau regions. It is therefore wholly possible that the amount of shortening of the crust of the earth resulting from reverse faults is more than compensated by elongation of normal faults, and thus the sum total of deformation by faulting result in dilatation rather than shortening of the crust of the earth.

Cleavage.—Cleavage has been supposed necessarily to indicate an important shortening of the crust of the earth.

It is, however, to be remarked that the shortening of cleavage must not be considered if the amount of shortening involved in the folding is counted for the same region; for cleavage is a phenomenon which may result from distortion under conditions of flowage, and the shortening represented by folding includes that involved in the simultaneous production of cleavage.

Moreover, cleavage is possible without any shortening whatever. I have shown in a previous paper[1] that cleavage may be produced by simple shearing motion parallel to the surface of the earth. The inclination of the cleavage will depend upon the amount of the shearing. Shearing of a very moderate amount will produce cleavage with dip as low as 30°. In the production of cleavage by shearing, each individual particle is shortened. Where shearing motion parallel to the surface of the earth results in cleavage inclined at 30°, the amount of shortening of each particle is about .4. However, the direction of shorten-

[1] Deformation of rocks, by C. R. Van Hise: Journ. Geol., Vol. IV, 1896 pp. 636–637, 868–872.

ing is inclined to the surface of the earth. The shortening involves an equivalent elongation in another direction. This elongation is at right angles to the direction of shortening, and is inclined to the surface of the earth in a direction opposite to

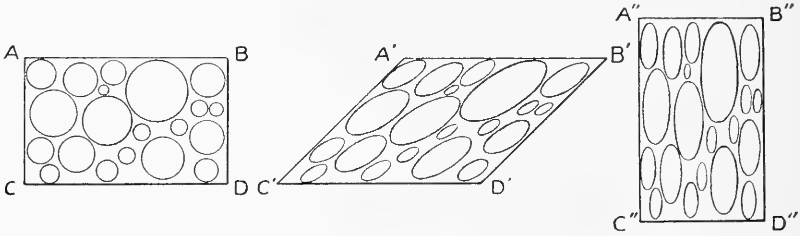


Fig. 11.—Inclined cleavage produced by shearing motion parallel to bedding without crustal shortening, and vertical cleavage produced with crustal shortening.

the direction of shortening. The forces producing a shear involve two couples, which at any given moment produce a tension in the direction of elongation and a compression in the direction of shortening. Thus, as a result of the work of the two couples in the production of cleavage by shearing parallel to the bedding, the direction of tension and the direction of shortening being inclined to the surface of the earth in opposite directions, are in such relations to each other at any given time and place that the total effect is neither elongation nor shortening of the crust of the earth.

This is illustrated by figure 11. The rectangle *ABCD* is deformed into the parallelogram *A′B′C′D′*, by shearing motion parallel to the bedding. The cleavage is parallel to the flattened ellipsoids. The area of the rectangle and parallelogram are the same, and also the line *A′B′* at the surface of the cleaved rock is of the same length as the line *AB* of the original rock before it was deformed and cleavage produced. The Ocoee slates of the Hiwassee river, west of McFarland for several miles, show a cleavage dipping to the southeast at an angle averaging about 30°. The beds are easily recognizable, and are very nearly horizontal. They show no bendings which can be dignified by the name of folds. However, even in this case the shearing motion parallel to the surface may have been accompanied by nonrotational distortion, as a result of horizontal thrust. The deformation resulting from such stresses is shown by figure 11. In this case the rectangle *ABCD* is deformed into the rectangle $A''B''C''D''$. The shortening is here great, and yet the beds are horizontal, although thickened. In nature the two cases may be combined in any proportion. In the Hiwassee slates already mentioned close observation shows slight crenulations of the generally horizontal strata. These suggest that the shearing motion parallel to the surface has been accompanied by horizontal shortening, and that both kinds of deformation are here combined. But the relative value of each is entirely unknown, and it is therefore impossible to give any estimate of the amount of crustal shortening involved in the deformation which resulted in the cleavage described.

We therefore conclude that while monoclinal cleavage over considerable areas may involve no crustal shortening, it is probable, in most cases of such cleavage, that there is a real crustal shortening, although it is impossible to estimate its amount.

After an inclined cleavage has been produced in any region, the conditions of deformation may change as a result of denudation, and fractures may form parallel to the cleavage. These fractures may be wide apart or close together. After these partings are produced, displacements may occur similar to those of joints (Fig. 10) or they may be closed by the falling down of the overhanging material, precisely the same as in the case of ordinary normal faults. The possible elongation resulting from these secondary movements may partly or fully compensate for the earlier movements resulting in shortening.

Fissility.— Fissility is a name applied to an actual close parting of a rock which results in the production of laminæ. Fissility may possibly develop as an independent structure, although it is believed that it is commonly a structure secondary to cleavage. It is further thought that fissility generally forms as the result of ruptures along shearing planes parallel to the cleavage, from compressive rather than tensile stresses. Where these ruptures occur close together, and there is slight differential movement, a distributive displacement may be produced, which is equivalent to a reverse fault, and which therefore results in crustal shortening, or the distributive displacements may be similar to those of the shearing joints of figure 10 and therefore result in crustal elongation. However, as in the case of cleavage just described, a region which is under compressive tangential stresses, and therefore is deformed by distributive faulting parallel to fissility, may later be under conditions of tensile tangential stresses. In this case partings will occur between the fissile laminæ, and elongation result. These elongations are strictly analogous to the elongation of normal faulting. The openings may be closed, as in the case of normal faulting, by a dropping down of the overhanging strata, or by methods of injection or cementation, as explained below.

Minute normal fault slips, secondary to cleavage or fissility, have been observed in the crystalline rocks near Blowing Rock, N. C. While during the formation of cleavage or fissility it is probable that shortening took place, it cannot be asserted that the subsequent elongation did not compensate for this, and it cannot be ascertained whether the total effect of the various deformations in this district resulted in elongation or shortening.

Vulcanism and cementation.— After a secondary structure has been produced, whether it be cleavage, fissility, joint, fault, or irregular structure, it may be taken advantage of by igneous intrusions in connection with deformation. These injections with the assistance of orogenic movements may greatly widen the openings so as to make places for great dikes. Such injections result in the local elongation of the crust of the earth. The injections may be divided into two classes, regular, approximately parallel injections, which take advantage of the above regular structures, and irregular injections.

Throughout considerable districts the amount of parallel injected materials is equal to, or surpasses the amount of original materials in which the regular secondary structures were produced, and thus there are large extensions of the areas affected.

This is finely illustrated by many districts of the Piedmont plateau crystalline and semicrystalline rocks. A convenient district in which to see the phenomena is that of New York. In the Manhattan gneiss in the vicinity of New Rochelle, the injected material in many places surpasses in quantity the amount of the original gneiss. Parallel injection is also finely illustrated by many of the districts of pre-Cambrian gneisses in eastern Canada, and western North America. In the latter region one of the most beautiful illustrations is that of the Madison Canyon gneiss in Montana. In these regions the intrusions seem to have occurred when the rocks were rather deep-seated, and doubtless in this zone intrusions are of much greater importance than nearer the surface. However, within a few thousand feet from the surface, extensive intrusions may take advantage of joints, faults, or radiating fractures. This is illustrated by the numerous granite dikes along joints in the Sierra Nevada granite; by the dikes of Crazy Mountain, Montana;[1] by the trap dikes of the Triassic of the Connecticut valley; by the dikes of Cape Ann, Massachusetts, where, according to Shaler,[2] the dikes occupy from 5 to 10 per cent. of the surface of the country; by the dikes of western Scotland;[3] and by the dikes of many other areas.

Besides the parallel and radiating intrusions just considered, great irregular intrusions of material have occurred on a vast scale. Irregular intrusions are especially numerous among the older rocks. The injected material may occupy a large part of the surfaces of the districts affected. The irregular injections of igneous material find lateral space largely by mashing or corrugating adjacent rocks, and this causes vertical expansion of the crust. Irregular intrusives may be found in the same districts in

[1] Livingston folio, by JOSEPH P. IDDINGS and WALTER H. WEED: Geol. Atlas of the United States, No. 1, 1894.

[2] The geology of Cape Ann, Massachusetts, by N. S. SHALER: 9th Ann. Rept. U. S. Geol. Survey, 1889, pp. 579–602.

[3] Geological map of Scotland, by SIR ARCHIBALD GEIKIE.

which the parallel injections are also found. Scores of illustrations of irregular intrusions, so extensive as to occupy important or even major parts of various districts, could be mentioned of any of the great groups of rocks. A number of instances are given on pages 49–50.

All openings which may be taken advantage of by injection may also be taken advantage of by underground water deposits, and thus by a combination of fracturing and cementation the area of the rocks is increased. That the rocks may thus receive an important extension of their surface area has been noted by Shaler.[1] While parallel and irregular cementation by water solution may not be so important as igneous injection in the lateral extension of rocks, it is a more widespread phenomenon, and undoubtedly has an important effect. Wherever openings have been produced in relatively deep-seated rocks (that is, in the lower part of the zone of fracture, and in the zone of combined fracture and flowage[2]) it appears to be the rule that cementation follows them, and thus rock material again occupies the entire space.

In regions where fissility has been developed, the laminæ are cemented by layers of infiltrated material, which in many places average as wide as the laminæ cemented. This is seen at many localities in the southern Appalachians. Cementation is not more important in closing the spaces between laminæ than it is in closing joints, faults, and irregular fractures. Such cementation may be found in the same districts as the depositions along the planes of fissility, and thus double the effect, or it may occur in districts in which fissility is unimportant. The Marquette district of Michigan finely illustrates the latter. Entire formations have been broken by innumerable joints, irregular cracks, or even brecciated. The openings are now entirely closed by cementation.[3] Since the time of this cementa-

[1] The crinetic hypothesis and mountain building, by N. S. SHALER: Science, Vol. XI, 1888, pp. 280–281.

[2] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 589–594, 601–603.

[3] The Marquette iron-bearing series of Michigan, by C. R. VAN HISE and W. S.

tion, when the rocks had neared the surface by denudation, other fractures formed which have not been cemented.

Thus throughout regions in which injection or cementation is extensive, there is complete evidence of important local extension of the crust of the earth. Moreover, in the case of the igneous material, it is certain that it acts as a wedge forcing the material apart. It also is possible that the wedging effect of cementation may not be unimportant. While it is probable that upon the average the deformations which produce the fractures taken advantage of by the entering material resulted in shortening the crust of the earth, it is by no means certain that in many cases at least the extension of cementation or injection did not largely compensate for the shortening due to the deformation.

Shortening of Algonkian and Archean rocks.— No one yet has been bold enough to attempt a quantitative estimate of the shortening represented by the older mountains, the stumps of which only remain. But oftentimes it has been stated in a general way that probably the pre-Cambrian folding, and consequent shortening, is as great or greater than all subsequent folding.[1] While I am not able to disprove this conjecture, it seems to me that the closeness of corrugation assumed as general for the ancient rock is not justified by the facts. I shall separately consider the Algonkian and Archean rocks because they are so dissimilar.

In many regions the Algonkian sediments are not closely plicated. For instance, in the Lake Superior region, including the Original Huronian district, the Keweenawan and Upper Huronian sediments are very gently folded. The same statement applies to other extensive areas of pre-Cambrian sediments in Canada. The sedimentary rocks of the Adirondacks are more severely folded, but still the folding is not close. The crystal-

BAYLEY: Mon. U. S. Geol. Survey, No. XXVIII, 1896, Pls. VII, VIII, IX, XXIII, and XXVI.

[1]A criticism on the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, p. 121. Origin of mountain ranges, by T. MELLARD READE: London, 1886, pp. 133–153.

line and semicrystalline rocks of the Blue Ridge in some places are closely folded and have secondary structures, but are in many places not closely corrugated. For instance, the quartz-schists of Tullulah mountains are in very gentle folds. The folding of the pre-Cambrian sediments in western America is also rather simple. The thick Grand Canyon series is but gently undulating. The Uinta sandstone is in a great simple arch. The thick pre-Cambrian series of Montana is gently folded. The pre-Cambrian of the Wasatch and Medicine Bow mountains are somewhat more closely corrugated, but not nearly so closely as many areas of Paleozoics in the New England region. However, there are some districts in which the folding is close and complex. This is the case with the Lower Huronian of the Vermilion and Menominee districts, and to less extent of the Marquette district, all in the Lake Superior region. The folding of the Original Laurentian district is of the most complex kind. However, even in these districts of close folding, it cannot be stated that the shortening is greater than is the case in the closely folded Tertiary rocks of the Alps.

Thus it appears that somewhat gentle folding is the rule with the pre-Paleozoic sedimentary rocks, as with the Paleozoic and post-Paleozoic, but in occasional districts the deformation, as in the later rocks, is of the most intense character. Therefore, during early geological periods, as during later geological time, orogenic movements have been concentrated along definite zones. Apparently since the beginning of Algonkian time large parts of the continents have escaped violent orogenic movements.

From the foregoing I do not mean to assert that the pre-Paleozoic sedimentary rocks are upon the average not more closely folded than later rocks. Indeed, the reverse must be the case, for the earlier rocks have partaken in subsequent foldings. The point upon which I insist is that there is no such great difference in the amount of deformation as has been thought by many.

However, it is in the Archean rocks that the apparent plications are most severe, but it is to be remembered that we have here no criterion upon which to make an accurate judgment, as bedding is missing. As seen (p. 29), cleavage is no criterion upon which to make estimates of shortening, and this is especially true of monoclinal cleavage, and such monoclinal cleavage is found in the Archean for great distances in various places, as for instance, in the Blue Ridge and Piedmont plateau, in southwest Montana, and in various areas in Canada. Also banding is no criterion, for, as has been seen in this paper, and shown in another place,[1] the regular banding in the Archean rocks is in many cases probably due to cementation and injection. However, it is often found in these ancient rocks that the secondary structures themselves, such as slatiness and schistosity, are folded into undulations, but these are in most cases rather gentle. For instance, the schistose structure of the Blue Ridge at Doe River is a single anticline, and on the Nacoochee-Hiwassee section are two anticlines separated by a syncline. The descriptions of Emmons and King show the same simplicity of structure for the Front Range of Colorado. The undulations of the schists are so gentle that they took them to be the remains of sediments, and gave an estimate of their thickness.

Finally, wherever we find exceedingly irregular and intricate structures in which no estimate can be made of the corrugations, even of the secondary structures, we are sure to find intrusive material intricately interposed, which may itself largely or wholly compensate for the shortening which we see.

I therefore conclude with the present state of knowledge, that we are wholly unable to make any quantitative estimate of the amount of crustal shortening involved in the deformation of the Archean rocks.

Longitudinal shortening of mountain systems.—In all past estimates which have been made of shortening in mountain-making only the transverse shortening has been considered, but in order to obtain a true estimate of the effects of deformation, it is necessary to consider the amount of longitudinal shortening. If it

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept., U. S. Geol. Survey, Pt. I, 1896, pp. 662–668, 684–688.

be agreed that complex deformation is the rule instead of the exception, as I have maintained in another place,[1] it is evident that longitudinal shortening is an important factor in deformation. As a consequence of cross folds, of reverse faults, and of other cross structures, it may be that the shortening of the crust of the earth in a longitudinal direction during the mountain-making processes is as great or greater than the transverse shortening.

This becomes evident as soon as the ratios between the length and breadth of the mountain chains are considered. The Appalachian system, in its broadest sense, extends from Alabama to the St. Lawrence River, a distance of about 1300 miles. Its breadth is about 75 to 100 miles. The ratio between the length and breadth is about 15 : 1. The Cordilleran system of North America in its broadest sense extends from western Alaska to southern Mexico, a distance of about 4800 miles. The breadth varies from 100 miles at the ends of the system to 1000 miles at the middle. But where this greater breadth occurs there are considerable distances between the different chains so that the folded area is probably not more than from one-half to one-fourth of the total amount. The average width of the folded part is probably somewhere between 300 and 500 miles. Thus the ratio between the length and breadth in this case would be between 16 : 1 and 10 : 1. The Andean system extends the entire length of South America, 4500 miles. This system is a comparatively narrow one, its average width being about 200 miles. The ratio of length to breadth in this case is therefore about 22 : 1.

It thus appears in the cases of these great mountain systems, if the longitudinal shortening involves from one-tenth to one-twentieth as much shortening as the transverse deformation per mile of linear distance, that the shortening of the crust of the earth as a result of the existence of the mountain systems is as great longitudinally as transversely.

In the case of some mountain systems which have considerable breadth as compared with their length, as for instance

[1] Loc. cit., p. 626.

the Pyrenees and the Himalayas, it appears that the longitudinal shortening is relatively more important than in the mountain systems in which the ratios between length and breadth are greater, as in the cases above mentioned. In the case of the Pyrenees this is beautifully brought out by the memoirs of Roussell, which show that cross folds are here important.[1]

In the introduction of the neglected element of longitudinal shortening into the problem of crustal shortening, in mountain-making, we have a factor which, contrary to those above considered, increases the total amount of crustal shortening. In order to properly estimate the effect of the formation of a mountain system upon the area of the surface of the earth, we must know its length and breadth now, as compared with the original length and breadth of the rocks making the mountains. The amount of crustal shortening is then known in surface area, the only proper unit in which comparison can be made, for shortening along one line is of little importance unless it extends over some finite distance transverse to that line. However, the introduction of this element of longitudinal shortening very greatly complicates the quantitative estimation of the amount of shortening of the earth, and such an estimation, in a direction transverse to the mountains, as has been shown, is a sufficiently difficult task if all the factors are taken into account which should be considered.

Although aside from the purpose of this paper, it may be remarked in passing that one of the difficulties which have appeared to confront geologists is not real. Geologists, assuming that all shortening is in a direction tranverse to the length of mountain systems, have been puzzled by the resultant conclusion that the shortening of the crust of the earth is so largely concentrated in a direction transverse to the meridians.[2] When

[1] Étudé stratigraphique des Pyrenees, by JOSEPH ROUSSELL: Bull. Carte Geol de la France, Tome VI, 1893–4, and especially accompanying Pls. I to V.

Étudé stratigraphique des massifs Mantagneux du Canigou et de L'Albere, by JOSEPH ROUSSELL: Bull. Carte Geol. de la France, Tome VIII, 1896–7.

[2] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, pp. 122–123.

one recognizes that longitudinal shortening may be as important as transverse shortening, this difficulty disappears.

Finally, to know the real effect of the deformation in mountain folding it is desirable to know not only the average closeness of the plications in two directions, but the depth to which this average closeness has been observed. In short, in order to obtain the most significant estimates of the effects of crustal shortening, not one dimension of a folded mountain mass, but three, length, breadth, and depth or thickness, should be taken in account. So far as I know, two of these factors, length and depth, have been wholly ignored in all estimates of shortening. The reason for this doubtless is that the difficulties in the way of the consideration of all these factors are insuperable, at least at present.

Shortening of removed formations.—Another element of uncertainty in giving estimates of crustal shortening is the unknown shortening of the rocks which have been removed by denudation. If, as has been supposed, circumferential shortening is at a maximum at the surface of the earth, the strata which have been most deformed have been removed from time to time. It would therefore follow, if we could estimate the amount of total shortening to which the rocks of the crust have been subjected, that this amount would fall short of the real shortening which the surface of the earth had undergone. The erosive forces as they cut off the mountain tops and distribute the material upon the border of the sea, smooth out the earth's wrinkles of age.

Conclusion.—If the argument of the foregoing pages holds, it is clear that we must begin at the beginning in making estimates of the amount of crustal shortening involved in mountain-making. The published estimates have ignored so many factors which must be considered before an estimate can have any quantitative value, that I am forced to the position that they are little more than guesses. It is therefore concluded that the amount of shortening of the crust of the earth, due to its deformation, is an entirely unknown quantity. By this I do not mean to imply that the crustal shortening has not been very great, but that as yet we can only make qualitative statements in reference to its amount; that quantitative statements are objectionable because they imply a definiteness of knowledge not warranted by the facts, and therefore stay the progress of investigation.

PART II. CAUSES OF CRUSTAL SHORTENING.

Secular cooling.— The first cause of contraction to be considered, and the only one ordinarily considered, is secular cooling. The amount of such contraction has been variously estimated. But the largest calculated amounts which the physicists will allow have always been disappointingly small to the geologists.

Mallet, on the hypothesis that the earth was liquid and had a mean temperature of 4000° F., has concluded that the earth "between its period of liquidity and its present state has shrunk in diameter by 189 miles at the least."[1] At that time, according to Mallet, the earth would have a mean radius of 4053.3 instead of 3958.8 miles. The surfaces of these spheres would be respectively about 206,457,000 and 196,942,000 square miles, and thus the surficial contraction of the earth would be about 9,515,000 square miles.

Dutton, making his calculation on another basis, concludes if the earth once had a nearly uniform temperature of 7000° F., that "if we were to assign thirty miles as the diminution of the earth's mean radius since the first formation of a cooled exterior, we should probably reach the utmost limit consistent with Fourier's theorem."[2] Taking the average radius of the earth as 3958.8 as before, the radius of the earth before contraction, according to Dutton, could not be more than 3988.8. The surface of this expanded earth would be about 199,938,000 square miles, which gives a surficial contraction of about 2,996,000 square miles.

[1] Volcanic energy: an attempt to develop its true origin and cosmical relations, by ROBERT MALLET: Trans. Roy. Soc., Vol. CLXIII, 1873, p. 205.

[2] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Jour. Sci., Vol. VIII, 1874, p. 121.

Fisher calculates that the radial contraction of the globe has been .65 miles since its temperature was 4000° F., and 1.9 miles if its temperature were ever 7000° F. These calculated contractions are so slight that it is not worth while to calculate the surficial contraction which would result from them.[1] Certainly, if Fisher's conclusion is approximately correct, loss of heat by secular cooling is not even an important cause for crustal shortening.

Darwin,[2] as a result of a discussion of the strains of the crust resulting from secular cooling, concludes that an earth 8000 miles in diameter would contract so that "in 10,000,000 years, 228,000 square miles of rock would be crumpled up and piled on top of the subjacent rocks."

The variation in the estimates above given is so great that the question not unnaturally arises as to whether the truth may not be far from any of them. Indeed Darwin says, with reference to his estimate, that "the numerical data with which we have to deal are all of them subject to wide limits of uncertainty."

All of the foregoing calculations as to the amount of heat lost by the earth are based upon the hypothesis that the earth has not had a higher average temperature than 7000° F. during geological time, and also on the hypothesis that the entire loss of heat is by conduction. If the present temperatures deep within the earth are to be measured by *many* thousands of degrees, as some believe, the amount of heat lost would be much greater than calculated, and the resultant contraction correspondingly important. Also the process of cooling would have been much more rapid if convectional currents assisted, by means of which the hotter material comparatively deep within the earth continued for a long time to be brought near or to the surface. It has been customary to consider the heat lost through convection as so small as to be negligible, and all calculations upon the amount of heat lost by secular cooling have ignored this quantity.

[1] Physics of the earth's crust, by OSMOND FISHER: London, 1881, p. 72.

[2] Note on C. Davison's paper on the straining of the earth's crust in cooling, by G. H. DARWIN: Phil. Trans. Roy. Soc., Vol. CLXXVIII, Pt. A, 1887, p. 249.

Loss of heat by convection is accomplished through transfers of magma and transfers of water.

If calculations are made of the loss of heat due to vulcanism, upon the basis of the volcanic materials brought to the surface of the earth at the present time, it is highly probable that the conclusion would be reached that this quantity is so small that it might be ignored. But one must remember that present vulcanism is no criterion by which to estimate the transfers of material which have resulted during past great periods of regional vulcanism. The transfers of enormous quantities of igneous material by vulcanism from deep within the earth to its outer shell or to the surface of the earth, described on page 48, strongly suggests that convectional currents have been a more important factor in the process of secular cooling that has been supposed. A large part of the heat which is carried toward the surface of the earth by magmatic convection is transferred only a part of the way by the liquid rock. For, as seen (p. 49), the intrusive rocks probably equal or exceed in quantity the extrusives, and deeper transfers may have occurred of which we have no definite knowledge. From the place where the magma is stayed the heat is brought to the surface in two ways. First, a part is transferred by conduction through the overlying mantle of rock. That such conduction occurs is shown by the fact that the temperature gradients in many districts receiving hotter material are higher than the average. Second, another part of the heat is brought to the surface by convection through underground waters. In this case the transfer of heat begun by the magma and by conduction is continued by water.

This brings us to the second agent by means of which the earth is losing heat through convectional currents. Underground water circulation everywhere pervades the outer zone of fracture at the present time, and doubtless has since a solid crust existed. That heat is brought to the surface of the earth by water is self-evident in the various districts of geysers and hot springs.

But in estimating the amount of heat which escapes by convectional transfer by underground waters, it is not sufficient to consider the random hot springs. If these were the basis of calculation it would indeed be unimportant. But if underground waters upon the average reach the surface with a slightly higher temperature than when they entered it, this may be a very important means by which heat is lost through convection. While difficult or impossible to prove by observation, I think it is unquestionable that underground waters must escape at a temperature upon the average somewhat higher than that with which they entered the earth. The average temperature of water when it enters the land may be presumably taken as that of the average of the surface of the earth at that locality. From this average temperature at the surface the temperature of the rocks increases downward. The vast quantities of water which at all times is taking an underground journey gains heat as a result of its contact with the warmer rocks. At another time I shall attempt to show that the water thus heated finally reaches the surface without losing all of the heat gained in its downward course. If this be so, there is constant loss of heat.

So far as I know, no attempt has ever been made to estimate the heat lost to the earth by means of the convectional underground currents of magma and water. While I am wholly unable to prove it, I have no doubt that the absolute quantity of such heat is enormous. The heat transferred by convection is to be added to the amount transferred by conduction.

As having an effect opposite to that of conduction and convection in lowering the average temperature of the earth, it is to be noted that as a result of changing rotation period (considered pp. 54–59) heat develops within the earth in two ways. First, heat is developed by tidal friction. Darwin states that he has "calculated that the heat generated in the interior of the earth in the course of the lengthening of the day from 5 hours 36 minutes to 23 hours 56 minutes would be sufficient, if applied all at once, to heat the whole earth's mass about 3000° F., supposing the earth to have the specific heat of iron."[1] Second,

[1] On the precession of a viscous spheroid, and on the remote history of the earth, by G. H. DARWIN: Phil. Trans. Roy. Soc., Vol. CLXX, Pt. II, 1879, p. 535.

consequent upon self-condensation, as a result of increased pressures coming from the greater effectiveness of gravity as the rotation period increased, additional heat within the earth would be developed. Also condensation of the earth as a result of change of physical state (see pp. 59–61) or in any other way, would result in the development of heat.

What the residual effect of these opposite neglected factors is upon the loss of heat as ordinarily calculated, it is impossible to say, and until the various estimates of the loss of heat approach one another more nearly than they do at present, it is not worth while to make a conjecture upon this subject.

If it be true that the temperature of the interior of the earth is much higher than premised in the calculations of heat lost during secular cooling, and if the convectional movements of magma and water are important means of refrigeration, it may be that heat has been transferred to the surface from much deeper within the earth than estimated by the physicists. Dutton[1] states that below "200 or 300 miles the cooling has, up to the present time, been extremely little." Davison affirms that below 400 miles the earth has not sensibly cooled.[2] These figures are based upon the hypothesis that the loss of heat is due wholly to conduction in a globe having a uniform initial temperature of 7000° F. If this hypothesis is incorrect, the hypothetical level of no lateral stress would be at a greater depth than calculated by Reade, Darwin, and Davison,—from 2 to 8 miles.[3]

Whatever the total loss of heat as a consequence of the various positive and negative factors, if we assume a liquid earth, it is certain that all of the resultant contraction is not available

[1] A criticism upon the contractional hypothesis, by C. E. Dutton: Am. Journ. Sci., Vol. VIII, 1874, p. 120.

[2] On the distribution of strain in the earth's crust resulting from secular cooling; with special reference to the growth of continents and the formation of mountain chains, by Charles Davison: Phil. Trans. Roy. Soc., Vol. CLXXVIII, Pt. A, 1887, p. 235.

[3] Estimates summarized in Manual of geology, by James D. Dana: 4th edition, 1895, pp. 384–385.

for crustal corrugations. None of the contraction is available to explain surficial deformation until after a solid outer shell has formed, either by solidification from the center or from the surface.

Also, making no hypothesis as to the early condition of the earth, the lessening of the solid surface available for corrugation does not include the full amount obtained by calculations based upon radial contraction. So far as the exterior shell was hotter than at present, its cooling would cause circumferential contraction, and consequent lessening diameter, without crustal corrugation, just as in the case of a steel jacket which in a heated condition is put upon the core of a gun, and which upon cooling shrinks.

Furthermore, as pointed out by Davison, the outer spherical shell might continue to contract circumferentially faster than the average contraction of the interior, because nearer the surface, and more rapidly losing heat.[1] This would cause tension in the outer part of the earth, just as in the case of the jacket on the gun, which, after it has shrunk to the core, continues to contract and so firmly clasps the core as to be under great tension; or just as a large steel ingot, at a high uniform temperature, by rapid cooling may so much more rapidly contract on its outer part than in its core as to form surface tensional cracks, because of the tensile stretching during the early stages of cooling.

How important this circumferential contraction is in the case of the earth is unknown. For we do not know the average temperature of the outer shell of the earth during early geological time, nor do we know very exactly its present temperature. We can only say that certainly some quantity must be subtracted from the total surficial decrease, resulting from loss of heat, in order to obtain the amount which is available to account for crustal shortening. Estimates which disregard this correction would be true only so far back in geological time as we can assume the temperature of the outer shell to be practically the same as at present.

[1] Loc. cit., pp. 231–242.

Also (as explained p. 53), so far as heat is lost by means of vulcanism the resultant earth contraction does not give an effect in crustal corrugations in addition to that due to the transfer of the magma.

But in estimating the effect of secular cooling upon corrugation, it must be borne in mind that the earth is so large that corrugations may have begun on one part of the crust, while other parts were still subject to tension, as explained, page 46. Under these circumstances corrugations might be produced which would be compensated by tensile cracks elsewhere. Such tensile cracks may become filled with sediment, with vein material, or with igneous injections. In so far as such compensated corrugations have been produced during the early history of the earth, these deformations are in excess of the amount which it is allowable to attribute to secular cooling. Davison suggests that early in the history of the earth the continental masses might have passed earlier from the stage of tension to the stage of compression than the sea beds, and that a part of the crustal flexures of the continents were, therefore, compensated by tensile fractures under the sea.[1]

It appears from the foregoing that the corrugations of the earth due to secular cooling follow from the difference in the loss of heat by conduction and by convection, and that developed by earth movements; and from an irregular distribution of the resultant stresses, which in some places may be tensile, and at the same time in other places be compressive. Ordinarily the loss of heat by conduction only has been considered. It is clear that in secular cooling we have an important, but probably by no means an adequate, cause to account for observed crustal deformation.

Vulcanism.—The second cause to which I shall appeal to explain shell corrugations is vulcanism.

At the outset it should be said that the quantity of igneous material which now reaches the surface of the earth is no criterion by which to judge past extrusions, for at times of regional

[1] Loc. cit., p. 241.

extrusions a quantity of magma may be emitted which surpasses the entire amount emitted between epochs of regional extrusions.

To appreciate the importance of regional extrusions of magma I need only to recall the Tertiary volcanic period, during which were produced the great lava plateaus, some of them thousands of feet in thickness, in western North America, Great Britain, Iceland, Franz Josef land, New Zealand, Abyssinia, and India. In western North America the area of these volcanics is to be estimated by hundreds of thousands of square miles. The Deccan traps of India are estimated to cover 200,000 square miles and for much of this area to be from 2000 feet to 6000 feet thick.[1] But the Tertiary volcanics with which we are acquainted are only a remnant of the quantity emitted ; for during Tertiary and post-Tertiary times, the erosion has been stupendous, and a large fraction of the material extruded has been converted into sedimentary rocks by means of the epigene agents.

While the volcanic rocks of the Tertiary period surpass in quantity the known igneous rocks of any previous period, it by no means follows that previous volcanic extrusions might not have been on a still vaster scale. For the further back we go, the larger is the fraction of the volcanic rocks of any given period which has been converted into sedimentary rocks by the epigene agents, and, furthermore, the proportion of the volcanics of a given period which is buried under sedimentary and igneous rocks ever increases as time passes by, so that but a small fraction of the formations bearing extrusives of great age is exposed, and in these formations, as has been seen, the larger parts of the extrusives have been destroyed.

Moreover, the extrusives are probably but the smaller part of igneous rocks. In another place I have suggested reasons why intrusives are more extensive than extrusives.[2] For the

[1] Geology of India, by R. D. OLDHAM : 2d ed., Calcutta, 1893, pp. 256, 263.

[2] Earth movements, by C. R. VAN HISE : Proc. Wis. Acad. Sci., Arts, and Letters, Vol. XI, 1898, pp. 495–496.

present purposes it is not necessary to enter into this discussion, but I wish to recall the facts as to the dominance of intrusives. Intrusive rocks are discoverable only after a region has been eroded, and it is therefore in these denuded regions that we are to look for evidence of intrusion. Beginning with the older periods, and confining our attention to America, we find that the Archean, so far as we can ascertain its original character, consists largely of modified plutonic rocks. Passing to the Algonkian, hardly an area is found in which intrusive rocks do not occupy a large percentage of the area. This is illustrated by the great masses of intrusive rocks in the Lake Superior region, which in many districts occupy large fractions of the areas. In the Rocky mountain region, in various districts, the Algonkian sedimentary rocks are subordinate to the simply enormous quantities of intrusive granite and other rocks. This is well illustrated by the Pikes Peak district, where, according to Cross,[1] the intrusive granite occupies two-thirds or three-fourths of the entire area of the one-half-square-degree quadrangle, and where the Algonkian sediments are mere fragments; by the Black Hills; by the Medicine Bow mountains, and many other ranges. Passing to the Paleozoic and Mesozoic, in almost every mountain region there are enormous masses of intrusives. This may be illustrated by the great batholiths[2] of granite in the Sierra Nevada and in the New England regions, by the laccoliths of the Henry mountains, of the Elk mountains and La Plata mountains, and by irregular intrusions, sills, and dikes, in almost every mountain district in the country. As yet the known Tertiary intrusives in America are not so important, but in Great Britain, where denudation has gone far, a vast quantity of the Tertiary intrusives has appeared. Doubtless in America also, when denudation shall have advanced far enough, correlative with the volcanics mentioned p. 48 will be found a great quantity of intrusive rocks.

[1] Pikes Peak folio, by WHITMAN CROSS: Geol. Atlas of the United States, No. 7, 1894.

[2] Suess's term *batholith* is here used in its strict etymological sense, with no reference to any theory as to how the magma was transferred, or as to whether or not it occupied previously existing spaces.

What is true of the intrusive rocks of America is true of other regions of the globe. I have selected America as an illustrative continent, because I know the facts of the field better there than elsewhere.

Any terms which one can use must fail to convey an adequate idea of the stupendous quantities of magma which have been introduced into the outer shell of the earth, or poured out upon its surface. It is clearly impossible to make even an approximate quantitative guess of the amount of igneous materials which have thus been intruded and extruded during geological times. Its quantity is certainly to be measured in tens of millions of cubic miles, rather than in smaller units.

Now in this transfer of earth material two things have happened. In so far as it has been taken from the nucleus, it has lessened its bulk. By the amount the nucleus has been lessened, the bulk of the shell has been increased.

Of this great mass which has thus migrated from the nucleus to the shell, a large proportion has stopped before reaching the surface. This is only possible by extension of the shell either vertically or laterally, or both. The forms of intrusives clearly show that both have locally occurred. Sills and laccoliths have mainly found a place to occupy by vertical extension of the shell, although to some extent lateral extension of the intruded layers (see p. 15) is also produced by them. It is equally clear that volcanic necks, dikes, and batholiths have largely found space by local lateral extension, although it is not doubted that the intrusion of such forms is also accompanied by vertical extension, and in the case of batholiths an important amount. Necks, dikes, and batholiths have formed in cracks and crevices, and wedged the walls apart, thus locally extending the crust, and giving surface which may be used in lateral mashing or corrugations elsewhere. In many cases the mashing and corrugation, and consequent thickening and vertical extension, are immediately adjacent to the intrusives. This is most marked in the case of the great batholiths. Adjacent to such enormous masses as the batholiths which are found in the Black Hills, in the Lake Superior region, in western Massachusetts, and in Great Britain, slaty or schistose structures parallel to the intrusives are common. These structures are conclusive evidence of lateral compression and vertical extension of the rocks intruded.

As already noted, the whole of the enormous mass of the intrusives and extrusives is to be subtracted from the mass of the nucleus and added to the mass of the shell. Of these two effects the expansion of the crust is without doubt by far the more important. If the nucleus of the earth be taken as having a radius of 3900 or more miles, radial contraction of one mile would involve a loss of volume of more than 190,000,000 cubic miles. A contraction of the radius of the earth of one mile, that is, from 3958.8 to 3957.8, would give a surficial lessening of only 100,000 square miles. In the supposed case of nucleal contraction of the radius by one mile, the 190,000,000 cubic miles of material would be available for additions to the crust. If it be supposed through geological time that this amount of material has been uniformly intruded within the outer ten miles of the crust of the earth, this would demand a surface space of 19,000,000 square miles, or about one-tenth of the earth's surface. As a consequence the material previously occupying this outer shell would be crushed so as to occupy nine-tenths of its original space, and this would involve enormous lateral crustal corrugation, with consequent thickening of the outer shell from ten miles to about eleven miles.

If it be supposed that the transfer through geological time from the nucleus to the outer five miles of the crust has been only one-tenth of the amount suggested in the above paragraph, the effect would still be great. Under this supposition, the radius of the nucleus of the earth as a result of igneous intrusions has contracted one-tenth of a mile, and as a consequence its surface has been lessened by about 10,000 square miles. This would involve an intrusion into the outer five miles of the crust of the earth of about 19,000,000 cubic miles of material, and I suspect that this is an underestimate rather than an overestimate of the igneous intrusions in this outer shell of the earth. Supposing that the igneous material is uniformly distributed vertically through the outer five miles, the material would occupy a surface space of about 4,800,000 square miles, with consequent surficial contraction and thickening of the remaining material of the crust. The surficial shortening of the original crust involved would in this case be about one-half as great as that due to secular cooling throughout geological time, as calculated by Mallet, and more than one and one-half times as great as that calculated by Dutton (see p. 41), even if it were supposed that the entire contraction were available for crustal corrugation.

Of course the above figures are hypothetical. The purpose of introducing them is to show the relative importance of crustal corrugation as a result of intrusion and nucleal contraction due to the transfer of magma, and to emphasize the fact that vulcanism is probably one of the great causes for shell corrugations, for two reasons. The intrusives occupy space in the shell. The nucleus shrinks by an amount equal to the combined igneous intrusions and extrusions. I am inclined to believe that this cause for crustal deformation is of the same order of magnitude as that due to secular cooling.

The fact that periods of considerable orogenic movements generally correspond with periods of great vulcanism is very suggestive and supports the conclusion as to the importance of the above transfers of igneous material, in explaining crustal corrugations. As a single illustration of this principle of correspondence may be mentioned the fact that the great Tertiary mountain-making period in which the Sierra Nevada range was last uplifted, in which the Coast Ranges and St. Elias Alps were formed, in which the Alps themselves were produced, and in which other mountain ranges were formed, is contemporaneous with the great Tertiary period of vulcanism.

By the foregoing I do not mean to imply that vulcanism is the initial cause of the orogenic movements. The initial causes are those assigned for earth contraction. The transfers of material followed as a result of the action of the initial causes, and thus is in a measure an effect, but also where the transfer occurs this is a further cause for crustal corrugation. Thus the transfers of magma are both effect and cause of crustal corrugations.

So far as I know, Lyell[1] was the first to suggest that there is a connection between folding and igneous intrusions. However, Fisher[2] went further than Lyell, and urged that vulcanism is the chief cause of crustal corrugation. His argument may be very briefly summarized as follows: Fissures form "through metamorphic changes. When these fissures originated below and are propagated upward, they become filled with elastic vapor, and compression results." According to Fisher, it is the expansive force of the vapor which makes the openings, and consequent corrugations, and these openings are occupied by the magma. So far as my present purposes are concerned it makes no difference how the intrusives found places for themselves. I merely insist upon the fact that somehow great spaces formerly occupied by solid rocks came to be occupied by the magma.

Shaler[3] has also appealed to igneous intrusions as a cause for mountain-making, and in a manner similar to Fisher. He thinks that in many places of New England the dikes occupy from one-twentieth to one-tenth of the superficial area.

However, neither Fisher nor Shaler consider the shrinkage of the nucleus of the earth due to the loss of the magma for both intruded and extruded materials, or the crustal corrugation which must result from this transfer of material.

In closing this part of the subject, it should be noted that crustal corrugation caused by transfers of magma involves no contraction of the earth nor lessening of its surface as a whole, except as magmatic transfer results in loss of heat by convection, as explained (p. 43). It may also be remarked that the earth contraction due to loss of heat caused by actual transfers of

[1] Principles of geology, by CHARLES LYELL: 10th ed., London, 1867, Vol. I, pp. 134–135.

[2] Physics of the earth's crust, by OSMOND FISHER: London, 1881, pp. 185–207, and pp. 284–286.

[3] The crinetic hypothesis and mountain-building, by N. S. SHALER: Science, Vol. XI, 1888, pp. 280–281.

magma to within the crust or upon its surface is not a cause for crustal corrugation in addition to that produced by the transfer itself.

Cementation.—Another cause which explains crustal corrugation is cementation (see pp. 34–35). In this process material is carried in a direction opposite to the transfers of vulcanism. In the outer zone of disintegration and decomposition material is everywhere taken into solution by underground waters, and carried to the openings below, where a part of it is deposited. Although the zone of solution which supplies the material at any time is narrow, material never fails, because this outer zone is ever migrating downward. Wherever at moderate depth during the process of deformation openings form, unless they are occupied by magma, they are gradually filled by water deposits, and thus there is local lateral extension, as in the case of vulcanism. The amount of material which thus migrates downward by means of underground waters cannot be quantitatively estimated, but it is certain that it is enormous.[1] In many regions where much deformed, comparatively deep-seated rocks have been brought to the surface, it is found that a measurable, and in some cases a considerable percentage of the entire space was once unoccupied and has been filled by cementation. The cemented rocks thus become a unit, which may be later deformed themselves, or transmit the thrusts to adjacent rocks, which may be deformed. In either case the shortening of the original material is compensated, at least in part, by the extension due to the cement, and thus the crustal corrugations are partly explained by water transfers of material.

Change of oblateness.— Peirce[2] and Darwin[3] have shown that as a result of tidal retardation the speed of rotation of the earth is decreasing, and that in the far distant past it rotated much more

[1] Earth movements, by C. R. Van Hise: Proc. Wis. Acad. Sci., Arts, and Letters, Vol. XI, 1898, pp. 511–512.

[2] The contraction of the earth, by B. Peirce: Proc. Am. Acad. Arts and Sci., Vol. VIII, 1873, pp. 106–108: Reprinted in Nature, Vol. III, 1871, p. 315.

[3] On the precession of a viscous spheroid, and on the remote history of the earth, by G. H. Darwin: Phil. Trans. Roy. Soc., Vol. CLXX, Pt. II, 1879, p. 535.

rapidly than at present, at one time possibly as fast as once in five and one-half hours. During this time of changing rotation, assuming that the geoid has accommodated itself to its period of rotation in the past as at present, Peirce states that there was a "diminution of oblateness arising from the diminished velocity of rotation upon the axis." He concludes on the hypothesis of homogeneity, when the earth rotated 4.236 times as fast as at present, that the equatorial radius would have been about 2½ per cent. greater than at present.

Taylor[1] later calculated that "when the day measured but six of our hours, the equatorial radius (assuming a true ellipsoid of revolution, and neglecting the small amount of contraction by loss of heat) would have been about one-tenth greater than it now is, or 4359 miles, and polar radius about one-sixth less, or 3291 miles. In other words, the poles would have been about 658 miles nearer the center of the earth than they are at present, and the equatorial protuberance about 396 miles higher than at present."

The discrepancy between these two results is so great that I referred the problem, for re-solution, to Professor C. S. Slichter, whose paper on this and other points immediately follows (pp. 65–78). I further asked that he obtain the amount of surficial contraction which would result from the change of oblateness. Upon the hypothesis of homogeneity, and with a period of rotation of five and one-half hours, he obtains a result which is practically the same as that of Peirce's. He finds that the earth, instead of having a mean radius of about 3959 miles, would have a polar radius of about 3736 miles, and an equatorial radius of about 4076 miles. This change from the past oblate spheroid to the present oblate spheroid would involve a contraction of the surface of the earth of about 210,000 square miles.

Change of pressure.—It further occurred to me that when the earth rotated more rapidly, the centrifugal force was greater than at present. When the rotation was four time as rapid as at

[1] On the crumpling of the earth's crust, by W. B. TAYLOR: Am. Jour. Sci., Vol. XXX, 1895, p. 257.

present the centrifugal force at the equator would be sixteen times greater than now. This being the case, it is evident that the effectiveness of gravity in producing interior pressures in the earth must have been less than at present. If the pressures were less, other things being equal, the earth would have less density than at present, and thus by a steady increase in the effectiveness of gravity during the time of decreasing rotation, we have a cause for contraction of the earth.

After reaching this qualitative conclusion, I asked Professor Slichter to handle the problem quantitatively. He finds when the period was five and one-half hours, on the hypothesis of homogeneity, that the pressure at the center of the earth was 1,688,000 atmospheres, instead of 1,772,000 atmospheres, or 4.8 per cent. less. Following Laplace's hypothesis that the earth is heterogeneous, and increases from a density of 2.7 at the surface to 10.74 at the center, and supposing that the heterogeneous oblate spheroid had an eccentricity of .4, the same as the homogeneous spheroid which has a five and one-half hour period, he finds that the pressures at the center would be 2,920,000, instead of about 3,000,000 atmospheres, or 2½ per cent. less than now. Further, as suggested by Professor Slichter, if it be supposed that during the geological history of the earth there has been a steady change from homogeneity in the direction of heterogeneity, the pressures at the centers of the spheroid, instead of increasing by the small amounts given, might have increased a much larger amount, depending upon the amount of differentiation (see Fig. 2, p. 72). The extreme case would be a change of pressure from those at the center of the homogeneous oblate spheroid when the period was five and one-half hours, that is, 1,688,000 atmospheres, to the present pressures of the heterogeneous spheroid, 3,000,000 atmospheres. In this case the pressures would have been 43.7 per cent. less than at present. It is not supposed that any such change of pressure has occurred during geological time, but the truth probably lies somewhere between this amount and the minimum, 2½ per cent., and probably much nearer the latter amount than the former.

Calculating on the basis of a heterogeneous spheroid at the beginning, *i. e.*, upon the minimum change of pressures of 2½ per cent., and assuming Laplace's laws of the relations of pressures and densities, that "The variation in pressure in the interior of the earth is proportional to the variation in the square of the density" (see p. 75), Professor Slichter finds the surface would be two-thirds of 1 per cent. greater than at present, or 1,700,000 square miles larger.

Moreover, when the surface and volume were greater than the present amounts, the effectiveness of gravity in producing pressures would be less than assumed, because of the greater size of the spheroid, so that the estimated enlargement of the surface is short of the truth. However, it does not appear practicable to make a quantitative estimate of the value of this element.

Another estimate of the amount of surficial lessening as a result of increased pressure may be made by a different line of reasoning, as follows: The most probable conjecture which can be made as to the average density which the material of the earth would have if it could all be placed under conditions of ordinary pressure and temperature is that obtained by Farrington as the average specific gravity of meteoric falls, 3.69.[1] The material of the crust probably does not represent the average composition of the earth, for differentiation must have occurred to some extent, upon any hypothesis as to the origin of the earth. All inferences as to the composition of the interior of the earth are based upon a considerable number of hypotheses, none of which are verifiable. However, the meteoric falls, not the finds, give us the density of the material which is now being added to the earth. This is probably a better guide as to the average composition of the earth than the average of meteoric finds, as suggested to me by Professor Chamberlin, because the stony falls of the past have probably largely disintegrated. Of course it is not certain that the material added at present to the

[1] The average specific gravity of meteorites, by O. C. Farrington: Journ. Geol., Vol. V, 1897, pp. 126–130.

earth from the interplanetary spaces represents the average composition of that out of which the earth segregated, but I can see no prospect that we shall be able to make any better conjecture of the average composition than that based upon meteoric falls. As already noted, the average specific gravity of such falls is 3.69, and the specific gravity of the earth is 5.67. Now, if this increased density is due to pressure, notwithstanding the high average temperature of the interior of the earth, it follows that the volume of the earth, as a result of pressure, has been reduced in the proportion of 5.67 to 3.69. The former number is 53.65 per cent. greater than the latter. If it be supposed that this percentage of expansion in volume would be inversely as the pressure at the center, a decrease of pressure at the center of 2½ per cent. would represent an increase of volume of 1.34 per cent., and an increase of superficial area of about 1,650,000 square miles. It will be noted that the above numbers are so manipulated as to give a minimum result. They could be handled in a different way and give a larger contraction of the surface.

The correspondence of this result with that obtained by Professor Slichter, 1,700,000, by an entirely independent line of calculation, is notable and suggests that Laplace's hypothesis as to the relations of pressure and densities within the earth, and the hypothesis that the average specific gravity of the earth material at ordinary pressures and temperatures is 3.69, and that the present density of the earth, 5.67, is due to pressure, may possibly both be approximately true.

The above calculations are based upon the hypothesis that the matter of the earth remains in the same condition under all pressures. It is subsequently seen that by a change from a liquid to a solid crystalline condition there is an important contraction. The increased pressure due to lessening rotation may have carried this change further than it would otherwise have gone. Gilbert has suggested to me that a moderate change of pressure within the earth may have acted similarly to the pressure upon a spring. Until the pressure reaches a certain amount but little deformation occurs, but at a certain stage a little added pressure produces important deformation. In another place (pp. 8–9) in this number of the JOURNAL, Powell suggests that the modulus of compressibility varies under different conditions, and that so slight a change of pressure as that due to unloading and loading by denudation, has caused important expansion and compression. If this be so, so important a change of pressure as results from change of the rotation period of the earth might have produced a more important effect upon its volume than would be obtained by supposing the modulus of compression to remain the same under all pressures.

It is not supposed that the numerical results given (pp. 56–58) for surficial lessening of the earth due to increased pressure, following upon lessened speed of rotation, approach exactness. However, it is to be noted that the numbers obtained by two different methods are concordant, and moreover, that all of the hypotheses used in obtaining these numbers have been so made as to obtain minimum results rather than maximum, and they are therefore probably much too small. It therefore appears highly probable that crustal shortening resulting from increased pressure as the speed of rotation of the earth has lessened, is one of the chief causes for earth contraction.

Change in physical condition.—Another cause of the earth's contraction is the change in the physical condition of the matter of the earth's interior. In so far as liquid material has changed to a solid amorphous material, this has produced contraction. Further, if liquid or solid amorphous material has changed to a crystalline condition, this has resulted in more important contraction.[1] This contraction is supposed to be due to the closer arrangement of the molecules. According to Delesse,[2] in passing from the crystalline to glassy state, granite decreases in density 9 to 11 per cent., syenite 8 to 9 per cent., diorite 6 to 8 per cent., dolerite 5 to 7 per cent., and trachyte 3 to 5 per cent. Barus has shown in the case of diabase, an

[1] So far as I am aware, Lyell was the first to suggest that deformation might result from a change from a liquid to a crystalline condition. (Principles of geology, by CHARLES LYELL: 10th ed., London, 1867, Vol I, pp. 134–135; Vol. II, p. 236.)

[2] See Manual of geology, by JAMES D. DANA: 4th ed., 1895, p. 265.

average rock, that it expands 13 per cent.[1] in changing from the crystalline to a liquid condition. The reverse passage from the liquid to the crystalline condition would involve a contraction of more than 12 per cent.

Even if the earth is now solid and crystalline to the center, as believed by some geologists, it by no means follows that this was the case through the major part of geological history. If the changes above mentioned have largely occurred during geological time, this has been a very important cause for contraction. However, there is no way by which the amount can be quantitatively estimated without involving so many uncertain hypotheses that it is not considered advisable to make the attempt.

Another subordinate cause for contraction is a change from less complex to more complex molecules. In so far as this change is involved in that of change from a liquid to an amorphous state or from either of these states to the crystalline condition, it has already been counted; but as a result of chemical interactions all substances, even crystalline compounds, tend to rearrange themselves under given conditions, especially where the temperature and pressure are great, so that they will have the most compact molecules. In so far as this has occurred, it is a cause for contraction, although its importance cannot be assumed to be great.

These changes in the physical state of matter and the consequent earth contraction are independent of the numerical results due to change of pressure and loss of heat given on a previous page; for all the estimates in reference to secular cooling and changing pressure are upon the hypothesis that the matter continues in the same state. The loss of heat and the increase of pressure are undoubtedly among the causes which promote change of physical condition, but in so far as change of state has occurred the resultant contraction must be added to the quantities assigned to the amounts due to secular cooling and increased pressure.

[1] The contraction of molten rock, by C. Barus: Am. Jour. Sci., Vol. XLII, 1891, pp. 498-499.

Loss of water and gas.—Finally, as suggested by Fisher,[1] nucleal contraction may have resulted from loss of originally occluded water. Chamberlin suggests that water and gas may have been emitted which have been lost to the earth.[2] Both of these losses would result in contraction of the nucleus. Probably the quantitative value of such contraction and consequent crustal shortening is small.

General.—Doubtless as the study of the earth continues, causes other than those assigned will be discovered for crustal shortening.

However, it is believed that the cumulative effects of the various causes assigned for nucleal contraction, and for crustal corrugation, are possibly sufficient to account for the phenomena of mountain-making.

We have seen that there are four important causes for crustal corrugation. These are secular cooling, vulcanism, change of oblateness, and change of pressures. Possibly there should be included among the important causes also that of change in physical condition and cementation.

It is impossible to make any accurate quantitative comparison of the several causes. However, it is to be noted that the change in surficial area due to oblateness of 210,000 square miles is about equal to that which Darwin estimated would result from secular cooling in 10,000,000 years, 228,000 square miles. It is to be further noted that the contraction due to increased pressures at a minimum estimation, 1,700,000 square miles, is 7½ times as great as the amount which Darwin estimated would occur in 10,000,000 years as the result of secular cooling, and is therefore equivalent to the effects of secular cooling for 75,000,000 years, or for a longer period than Darwin allows for the history of the earth since the separation of the earth-moon couple. At present we are, and probably we shall long continue to be, unable to give any accurate quantitative value to the crustal shortening

[1] Physics of the earth's crust, by OSMOND FISHER: London, 1861, pp. 87, 180, 218.

[2] A group of hypotheses bearing on climatic changes, by T. C. CHAMBERLIN: JOURN. GEOL., Vol. V, 1897, pp. 656–668.

resulting from vulcanism and cementation and from change in physical condition, but it appears possible, perhaps probable (see pp. 47–52), that in vulcanism we have an explanation of as large, or even a larger, fraction of the phenomena of crustal corrugations than is furnished by any other single cause.

The various causes for crustal shortening may be divided into two classes: (1) those which involve a change in the volume of the earth; and, (2) those which involve transfers of material. (1) The loss of heat due to secular cooling, the increased pressures due to lessening rotation, and the changes of physical condition involve a contractional change of volume. Changing oblateness due to changing rotation, vulcanism, cementation and nucleal loss of water and gas, involve no appreciable change of volume. (2) Changing oblateness is only possible by deep-seated transfers of material which cause a change in the form of the earth resulting in surficial contraction. Vulcanism results in crustal expansion and nucleal contraction, and therefore in crustal corrugation. The surficial expansion due to cementation compensates for a part of the crustal corrugation. Loss of water and gas produces slight nucleal contraction, and consequently some crustal corrugation.

Furthermore, it is to be remembered that the entire effect of all these changes is available to account for crustal corrugation, with the exception of contraction due to loss of heat, which, as explained (pp. 44–45), is only partially available to account for crustal deformation. Upon the other hand, the transfers of material by vulcanism from the nucleus to within the shell has an added effect in producing crustal corrugation much greater than that due to nucleal contraction.

The crustal shortening due to changing oblateness, and increased pressures resulting from lessening rotation must have been large in the remote past. According to Darwin,[1] 56,810,000 years ago the rotation period of the earth was 6 hours 45 minutes, and 46,300,000 years ago the period was 15 hours 30

[1] On the precession of a viscous spheroid and on the remote history of the earth, by G. H. Darwin: Phil. Trans. Roy. Soc., Vol. CLXX, Pt. 2, 1897, p. 494.

minutes, *i. e.*, in about 10,500,000 years the period changed 8 hours and 45 minutes. For the entire 46,300,000 years which have since elapsed the change in period was from 15 hours 30 minutes to 24 hours or a change of 9 hours 30 minutes, but a little more than the change for the previous 10,500,000 years. At the present time, changing rotation has ceased to be a cause for mountain-making of any importance, for, according to Cayley,[1] the acceleration of the moon's motion due to tidal friction is less than 6 seconds per century.

The chief effects in mountain-making of changing oblateness and increased pressures resulting from change of rotation, as noted by Peirce in reference to the former, would be concentrated in the equatorial regions. The mountains are more numerous and higher at low latitudes than at high latitudes. The only way that this can be attributed to decreasing rotation is to suppose that the mountain-making localities were determined by the changes due to these causes, and that subsequent deformations have continued along the old zones of weakness.

However, decreasing oblateness and increasing pressures are available to explain the great deformation of the older rocks, and especially those of the Archean and Algonkian eras.

The amount of contraction which can be attributed to loss of heat is also a steadily decreasing quantity. However, in vulcanism we find a cause for crustal corrugation perhaps as potent now as at any time since the beginning of the Algonkian. Indeed, as has been seen (p. 48), the greatest volcanic epoch of which we have certain knowledge is late Tertiary time, and contemporaneous with this was the great Tertiary period of mountain-making.

It is clear that the explanation offered for crustal deformation is complex. The theory is a combined contractional and transfer theory. Moreover, the contraction, instead of being assigned to a single cause, secular cooling, is assigned to this and to increased pressure and changing physical condition. Also

[1] On the secular acceleration of the mean movement of the moon, by ARTHUR CAYLEY: Monthly Notices, Roy. Astr. Soc., Vol. XXII, 1862, pp. 171–230.

the transfers of material are of several kinds, but those of vulcanism and those of changing oblateness are the more important. The conclusions reached may therefore be considered as illustrating Chamberlin's method of multiple working hypotheses.

It is to be noted in conclusion that the argument of the above paper is independent of any theory of the origin of the earth, and of any theory of the condition of its interior, provided it is largely limited in its application to the time since the earth in some way had attained approximately its present mass. Furthermore, the contractional and corrugating effects dependent upon changing rotation involve the hypothesis that at one time the earth rotated upon its axis several times more rapidly than at present. If a more rapid rotational period be assumed than that discussed, the resultant effects would be correspondingly greater. But however the earth originated, and whatever the condition of the interior, the considerations offered which should be taken into account in estimates of crustal shortening are applicable.

C. R. Van Hise.

NOTE ON THE PRESSURE WITHIN THE EARTH.

It is the object of the present paper to briefly consider the magnitude of the pressures within the earth-spheroid, especially as influenced by the changes that have been brought about in the ellipticity of the earth's figure by its changing rotation period.

Darwin, in considering the stability of the moon-earth couple, says it seems improbable that a rotation of the earth in a little over five hours, with an ellipticity of $\frac{1}{12}$, would render the system unstable, and it hardly seems likely that better data and more perfect solution would largely affect the result, so as to make the period of revolution of the two bodies in the initial configuration very much less than five hours.[1] If the earth be assumed homogeneous throughout, as was done by Darwin in his investigations, with a density equal to the present mean density, it is a simple matter to calculate the pressures within the earth for any given eccentricity of its outer crust; and these eccentricities are, in turn, easily deducible from a knowledge of the rotation period. A table on page 327 of Part II of Thompson and Tait's Natural Philosophy gives us at once the rotation periods corresponding to various values of the eccentricity. We there find that

$e = .5$ corresponds to a rotation period of 15,730 seconds or 4½ hours.
$e = .4$ corresponds to a rotation period of 19,780 seconds or 5½ hours.

I have assumed that the separation of the moon-earth couple took place at a time when the rotation period of the earth was intermediate to the values just given, and that it would be sufficient for the purposes of geology to trace, from the epoch indicated, the changes in pressure that have taken place in the earth's interior. If it be assumed that the spheroids of eccen-

[1] Phil. Trans., 1879, Part 2, p. 536.

tricities .5 and .4 had the same volume and mass as the present earth, the polar and equatorial axes can readily be computed. Using Clark's value of the mean radius and volume, 6.3709×10^8 cm. (3958.8 mi.) and 1.0832×10^{27} cc. respectively, and Baily's value of the mean density, 5.67, I obtain the constants as given in lines 5–8 of Table I. The change of shape from the spherical

TABLE I.

		Spheroid 1	Spheroid 2	Sphere	Units
1	Eccentricity $= e$.	.5	.4	0	
2	Ellipticity $= \epsilon$ ...	.134	.0835	0	
3	Mean radius $= a_0$	6.3709×10^8 cc.	$=$ 3958.8 mi.		
4	Volume	1.0832×10^{27} cm.	$= 2.5988 \times 10^{11}$ cu. mi.		
5	Surface.........	197,800,000	197,160,000	196,950,000	sq. miles
6	Excess of surface over that of sphere........	850,000	210,000		sq. miles
7	Semi-polar axis..	3597	3736	3959	miles
8	Semi-equatorial axis..........	4155	4076	3959	miles
9	Attraction at pole	995.6	990.2	981	dynes
10	Attraction at equator.......	968.8	975.0	981	dynes
11	Rotation period if homogeneous..	15730	19780		seconds
12	Centripetal acceleration at equator...........	106.7	66.16		dynes
13	Gravity at equator...........	862.1	908.8		dynes
14	Pressure at center if homogeneous	1.633	1.688	1.772	million atmospheres
15	Ratio to pressure at center of sphere........	92.2	95.2		per cent.
16	Pressure at center if heterogeneous	2.88	2.92	3.00	million atmospheres
17	Ratio to pressure at center of sphere	96	97.5		per cent.
18	Change of volume, Laplacian law...........	2.1	1.3		per cent.
19	Percentage change in area, Laplacian law.	1.34	8.5		per cent.
20	Actual change in area, Laplacian law...........	2,700,000	1,700,000		sq. miles

form requires, of course, a change in area of surface, which change is noted in lines 5 and 6 of this table. The change in shape of the spheroid would likewise change the values of the attraction of gravitation at all points of the surface. The value of the attraction at the poles would be greater than the mean attraction on the surface of the present earth, while the attraction at the equator would be less. These values are placed in lines 9 and 10 of Table I. The determination of the attraction has been made in terms of the eccentricity from accurate formulas.[1] The values could have been computed in terms of the ellipticity[2] from the following approximate formulas, in which the square of the ellipticity has been neglected:

$$\text{attraction at pole} = (1 + \tfrac{2}{15}\,\epsilon)\, g_0.$$
$$\text{attraction at equator} = (1 - \tfrac{1}{15}\,\epsilon)\, g_0.$$

Here g_0 is the attraction at the surface of the same mass in spherical form.

It should be noted in this connection that the ellipticities of the spheroids under consideration are so large as to render the omission of their squares unsafe, although, as is the case in the present paper, no great importance is to be attached to the actual figures of the results. For a like reason, Clairaut's theorem may not be used with much accuracy in checking results.

Besides the reduction in the attraction at the equator due to the change in the shape of the earth, there was formerly a still further loss due to the high centripetal acceleration accompanying the short rotation period. In the case of $e = .5$, this amounted to 107 dynes, and in the case of $e = .4$ to 66 dynes; these values subtracted from the values of the attraction previously determined, give the value of equatorial gravity placed in line 13 of Table I.

The values of gravity and pressure at any point on the polar or equatorial axis of the spheroid may now be determined. If

[1] See PRATT'S Figure of the Earth, 4th ed., p. 98.

[2] The ellipticity is the difference between major and minor axes divided by the major axis. I have represented it by the Greek ϵ, and have represented the eccentricity by e.

X_x represents the value of gravity at any point distant x from the center of the spheroid on an equatorial radius, and if Y_y represents the corresponding quantity for a point on the polar axis, and if g_e and g_p are the values of gravity at the equator and at the pole respectively, and if a and b are the semi-polar and semi-equatorial axes, then we have

$$X_x = \frac{g_e\,x}{a}; \qquad Y_y = \frac{g_p\,y}{b}.$$

Also if P_x and P_y represent the pressure at the same points, then

$$P_x = \frac{\rho_0}{2}\,g_e\left(a - \frac{x^2}{a}\right),$$

$$P_y = \frac{\rho_0}{2}\,g_p\left(b - \frac{y^2}{b}\right),$$

in which ρ_0 is the density of the homogeneous spheroid, and in which the other letters have the same significance as above. The following table gives the pressures at various distances from the center. The unit pressure is a million atmospheres of 10^6 dynes per sq. cm.

TABLE II.

PRESSURES WITHIN HOMOGENEOUS SPHEROIDS OF VARIOUS ECCENTRICITIES.

Distance from center along polar or equ. axis	$e=.5$	$e=.4$	$e=0$	Distance from center along polar or equ. axis	$e=.5$	$e=.4$	$e=0$
0	1.633	1.688	1.772	.6	1.043	1.079	1.133
.1	1.615	1.669	1.754	.7	.833	.862	.904
.2	1.567	1.618	1.700	.8	.588	.608	.638
.3	1.485	1.533	1.613	.9	.310	.321	.337
.4	1.370	1.417	1.488	1.0	.0	.0	.0
.5	1.224	1.264	1.328				

The pressures for $e=.5$ and for the sphere are shown graphically by the lower curves in Fig. 2. The line OX corresponds to either the polar or equatorial radius, as we may be pleased to consider it, but is represented, of course, as of length 10 in each case. The pressures at any other point in the spheroid can be found by drawing the equipotential surfaces; for on each of these the pressure is everywhere constant and equal, of course, to the value of the pressure at the intersection of the equipotential surface with the polar and equatorial radii.

The pressures for $e=.4$ are not shown in the diagram, but they are not greatly different from those shown for $e=.5$. It should be noticed that the pressures for $e=.5$ are about 8 per cent. less than for the spherical form, and for $e=.4$ the pressures are about 5 per cent. less than for the spherical form.

The results above given were worked out on the supposition that the spheroid was homogeneous, having its density equal to the mean density of the earth. Of course the actual spheroid is not homogeneous, but heterogeneous, with the density increasing from surface to center. We know that the density of the surface material of the earth is approximately 2.75, and that the mean density is about twice as great. The exact law of variation of density in the interior cannot be said to be known, yet the law assigned by Laplace nearly a century ago is generally accepted as close to the truth. This law of density is as follows:

$$\rho = \frac{4.365\, a_0}{a} \sin \frac{2.4605\, a}{a_0};$$

in which ρ is the density of the stratum whose mean radius is a, the mean radius of the surface being a_0. The numerical constants are determined on the supposition that the surface density is 2.75 and the mean density twice as great. The variation according to this law is shown graphically by the heavily drawn curve of Fig. 3. An inspection of this diagram shows that the density increases quite uniformly for a considerable distance as we pass from the surface towards the center. We finally come to a central nucleus of nearly uniform density. The density at the center is 10:74.

The Laplacian law of density agrees well with the measurements of precession, and is probably as near to the truth as the measured values of the earth's mean density.

An exact method for determining the pressures within a heterogeneous spheroid without knowing its rotation period is not known to me. Even if the rotation period of the heterogeneous spheroids of eccentricities .5 and .4 were known, a computation of pressures would require the neglect of the squares of the ellipticities, which, in the case of ellipticities so large, would give results poorly compensating for the labor involved. I have, therefore, contented myself with two rough processes of approximation.

The pressure within a sphere in which the density is that of the Laplacian law can readily be computed by direct integration.[1] The result may be expressed as follows:

$$p = g_0 \, [2.7388] \left(\frac{\sin^2 n \, (2.4605)}{n^2} - 0.396 \right) \text{ atmospheres.}$$

In this formula, p is the pressure in atmospheres of 10^6 dynes per square cm. each, at the fractional distance n from the center of the earth, the radius being taken equal to unity for convenience. The bracket [2.7388] indicates the logarithm of a factor, and g_0 is the value of gravity at the surface.

Returning now to Fig. 1, it will be noticed that I have represented a section of the spheroid and two spheres, in contact at *N*. We shall suppose that the spheroid *A* is heterogeneous, with Laplace's law of density, and that sphere *B* is a sphere of same volume, same density, and the same law of density as the spheroid *A*. The sphere *C* is inscribed within the spheroid *A*, and has, I shall suppose, the same mean density and the same law of density as the latter. Then it is easy to see, since the law of density is such that the density increases towards the center, that the pressure at the center *O* of the sphere *C* must be less than the pressure at the center *O* of the spheroid *A*. Likewise, for the same law of density, the pressure at the point *O* of the sphere *B* is greater than the pressure at the center *O* of the spheroid *A*. The pressures at the point *O* within the spheres can be obtained by the formula above given, and as the pressure at the center of the spheroid is intermediate in value to those thus obtained, its value becomes approximately determined.

[1] See Osmond Fisher, Physics of the Earth's Crust, p. 32.

The pressures for the earth, calling the radius 10, are as follows, the unit being a million atmospheres:

Distance from center	Pressure in million atmospheres	Distance from center	Pressure in million atmospheres
0	3.00	6	1.25
1	2.94	7	0.85
2	2.74	8	0.50
3	2.46	9	0.21
4	2.09	10	0.00
5	1.67		

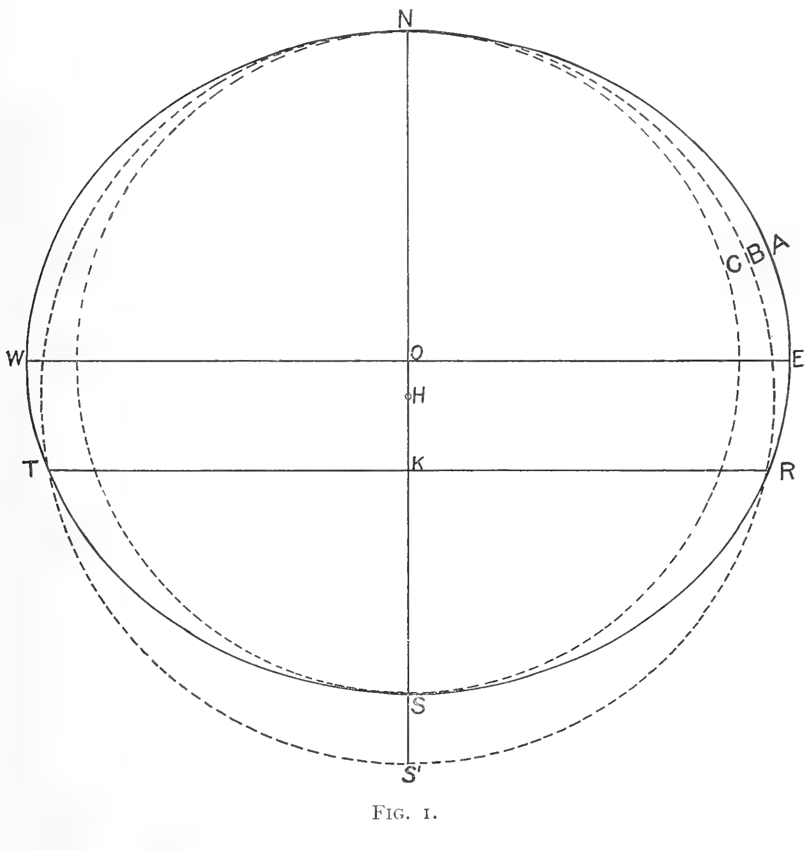


FIG. 1.

The pressures in the spheroid if $e=.5$ are about 4 per cent less, and if $e=.4$ are about $2\frac{1}{2}$ per cent. less than pressures

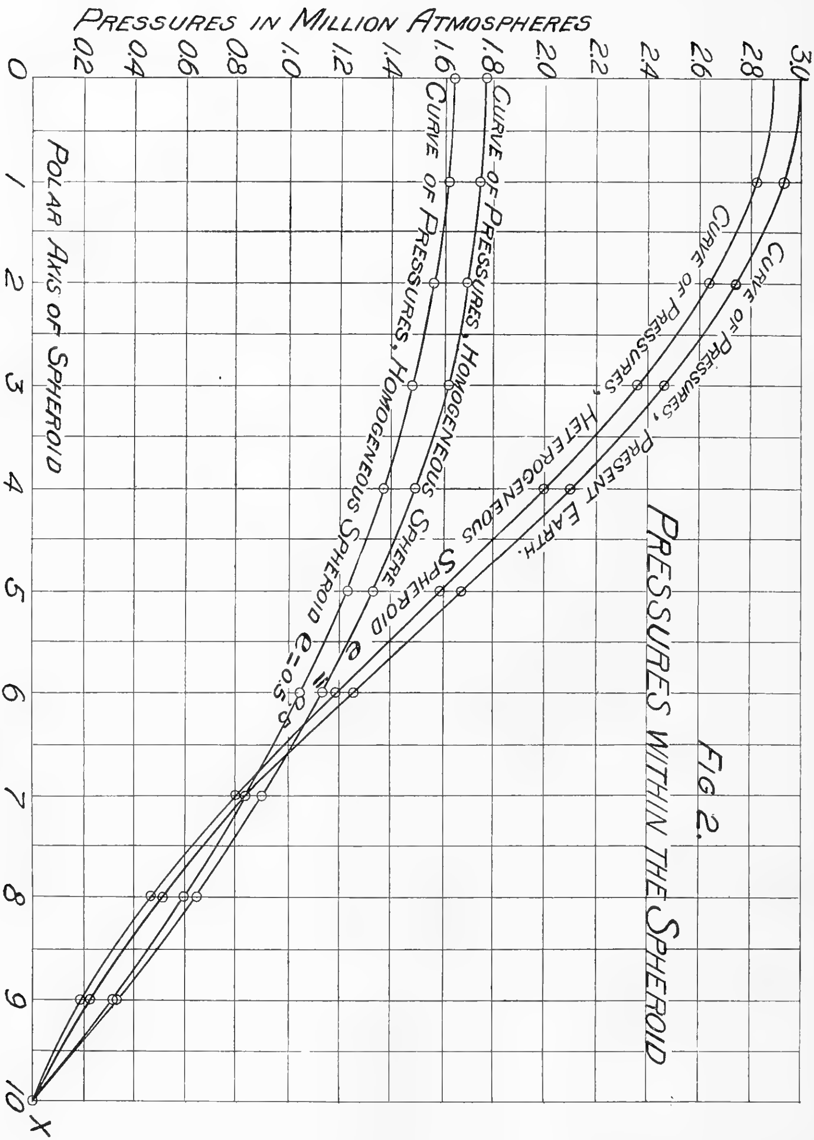

PRESSURES IN MILLION ATMOSPHERES
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
POLAR AXIS OF SPHEROID
1
2
3
4
5
6
7
8
9
10
X
CURVE OF PRESSURES, HOMOGENEOUS SPHEROID e=0.5
CURVE OF PRESSURES, HOMOGENEOUS SPHERE e=0
CURVE OF PRESSURES, HETEROGENEOUS SPHEROID e=0.5
CURVE OF PRESSURES, PRESENT EARTH.
PRESSURES WITHIN THE SPHEROID
FIG 2.

FIG. 2.

in present earth. The pressures in the present earth and in the heterogeneous spheroid if $e = .5$ are shown graphically by the upper curves in Fig. 2. The greatest rate of change of pressures is seen to be at a point about .65 of the distance from the center to the surface.

Whatever the law of increase of density within the spheroid, provided only that the density continually increases as we approach the center, we may easily derive the following theorem:

The pressure at the center of a heterogeneous spheroid differs from the pressure at the center of the same matter in the spherical form, by a fractional amount which is less than two-thirds the ellipticity of the spheroid.

Thus if the ellipticity is .06, the pressure at the center will be not to exceed 4 per cent. less than if the matter was in the spherical form. This shows that the changes in pressure due to the changing ellipticity of the earth are limited in amount, although important, and of the same order of magnitude as the ellipticity.

Another roughly approximate method of estimating the pressures within the heterogeneous spheroid consists in assuming that all the strata of equal density have the same ellipticity as the surface. As a matter of fact, the ellipticity of the strata decrease as we approach the center by a law which may be deduced from the Laplacian law of density, and which is represented graphically by the broken line in Fig. 3. The ordinate of this curve gives the ratio of the ellipticity of a stratum to the ellipticity of the surface. It will be observed that the ellipticity of strata near the center is about 80.72 per cent. of the surface value. The actual case, then, does not differ from the assumed case of uniform ellipticity by a very large amount. It leads to the result that the change in pressure at the center of the earth due to a change in the ellipticity of the outer crust, is nearly the same in amount as if the earth were homogeneous, although the percentage change is much less than in the latter case. The relation between the ellipticity of any stratum to surface ellipticity is given by the equation :

$$\epsilon = \frac{2}{a^2}\left(1 - \frac{q^2 a^2}{3(1 - q a \cot q a)}\right)\epsilon_0$$

in which ϵ is the ellipticity of the stratum whose mean radius is a, ϵ_0 is the ellipticity of the surface, and $q = \frac{2.4605}{a_0}$[1]

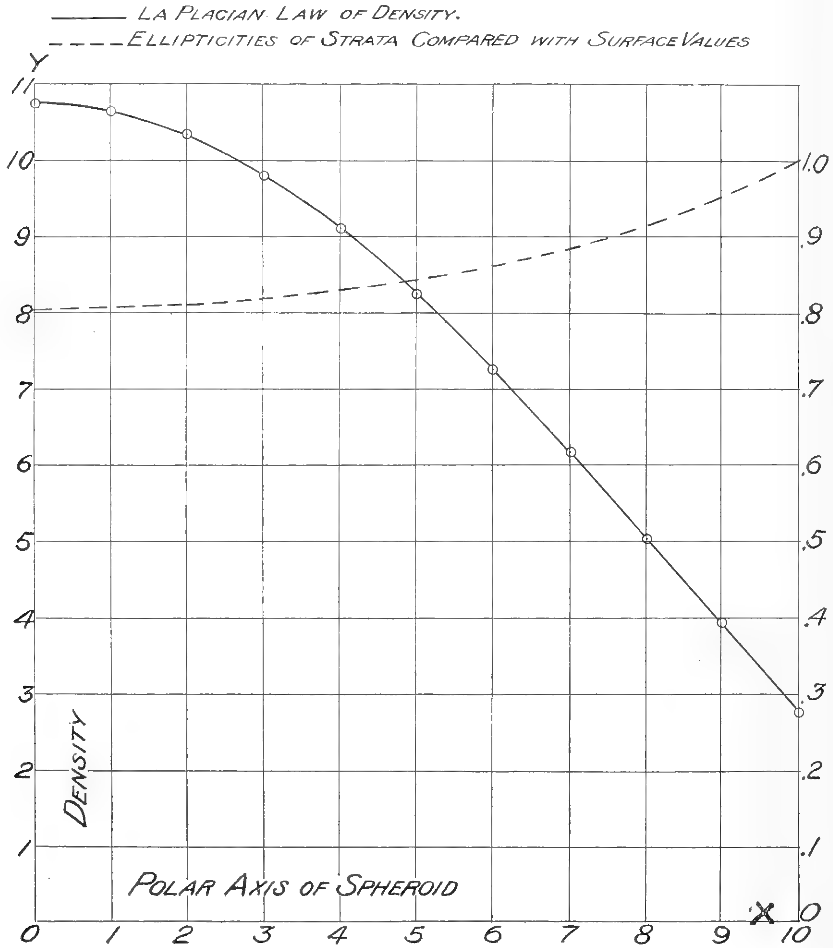


FIG. 3.

[1] See Thompson and Tait, II, p. 410; Pratt, Figure of the Earth, 4th ed., p. 115; Clarke, Geodosy, p. 84.

The decrease in the size of the earth that would be brought about by the increase of internal pressure discussed above, may be computed, if it be assumed that the high density in the interior of the earth is due alone to the compressibility of matter under the enormous pressures there present. Laplace, as a matter of fact, began by assigning a law of compressibility and thence deducing the law of density; however, his law of density might be close to the truth and yet be not entirely controlled by the pressure. The equation

$$\rho = 4.365 \frac{a_0}{a} \sin \frac{2.4605\, a}{a_0}$$

leads to the following relation connecting pressure and density.[1]

$$d\,p = k\,d\,(\rho^2)$$

or, as stated by Laplace: *The variation in pressure in the interior of the earth is proportional to the variation in the square of the density.*

The law of compressibility of gases—"Boyle's Law"—and the law of elasticity for small compressions in solids—"Hooke's Law"—state that the variation in density is directly proportional to the variation in pressure. Thus Laplace's law assumes a compressibility which is less than that given by either of the laws just named, an assumption which is, in itself, very reasonable.

From the above equation we derive

$$k\,\rho^2 = p + c$$

and determining the constants on the supposition that the surface density is 2.75, and the central density 10.74, we conclude that

$$(.02575)\,\rho^2 = p + .1947$$

in which p must be given in terms of a million atmospheres as unit. To determine the change in density due to a small change in pressure we may write,

$$\frac{d\,p}{p + c} = 2\,\frac{d\,\rho}{\rho},$$

or

$$\frac{d\,p}{p}\left(\frac{p}{p+c}\right) = 2\,\frac{d\,\rho}{\rho}.$$

[1] See O'Brien, Math. Tracts, p. 39; Pratt, p. 113; Thompson and Tait, II, p. 403.

Now if the change in pressure that has taken place is 4 per cent., we may place

$$\frac{dp}{p} = \frac{4}{100},$$

and, since c is small in comparison with p,

$$\frac{d\rho}{\rho} = \tfrac{1}{2}\frac{dp}{p} - n = \frac{2}{100} - n$$

in which n is a number with a small average value. Therefore, we may assume that, on the average, the change in density is about half the change in pressure. Taking the ratio as one-half, we can compute the change in volume of the spheroid for a given change in internal pressure, since, of course, volume is inversely proportional to density. I have placed results of this computation in the line 18 of Table I.

The decrease in the size of the earth due to the increase of internal pressures must likwise reduce the extent of the outer surface. If v and s represent the volume and surface of the sphere,

$$\frac{ds}{s} = \tfrac{2}{3}\frac{dv}{v},$$

or, for small changes, the change in surface is two-thirds the change in volume. This gives a reduction in surface amounting to about 1.3 per cent. for the spheroid $e = .5$, and .85 per cent. for the spheroid $e = .4$, or, in square miles, a reduction in surface of about 2,700,000 square miles, and 1,700,000 square miles respectively.

The compressibility of matter under high pressure and high temperature cannot be said to be known experimentally. Thompson and Tait, however, on page 415 of Part II, estimate for the average material at the surface of the earth, the compressibility that must theoretically follow from Laplace's law, and give as the result :

Melted lava, by Laplace's law - - 4.42

They also give actual experimental determinations of compressibility as follows :[1]

[1] If the radius of the earth, 6.37×10^8, be divided by each of these numbers and if

Alcohol	37.
Water	29.
Mercury	27.
Glass	5.0
Copper	8.1
Iron	4.1

The comparison, they remark, may well be considered as decidedly not adverse to Laplace's law. We may thus infer that it is far from unreasonable to hold that the high density of the interior of the earth is entirely due to the enormous pressures there present and hence it is not unreasonable to hold that the diminution in the earth's surface, pointed out above, has actually taken place. Yet, whatever future experiments may show in regard to the compressibility of melted rock, we certainly must believe that the enormous pressure at the center of the earth does have some effect, and, indeed, a large effect, in making the density high in that part of the interior.

In addition to the results which must follow from a former high rotation period of the earth and large ellipticity, important increments to the internal pressures must have taken place, if any change in the interior from homogeneity to heterogeneity has occurred. Notwithstanding the current computed results for the cooling of the earth, it seems reasonable to suppose that the energy in the interior of the earth, was, within geological times, distributed with greater homogeneity than it is at present. If any such change in the distribution of energy has taken place, then the density of the earth's interior has likewise progressed from homogeneity to heterogeneity. The curves given in Fig. 2 show that the pressure at the center of a homogeneous spheroid is only about half the pressure at the center of the present earth. Therefore, any progress that has been made

each quotient thus obtained be multiplied by 981 times the density of the substance, the result will be the *volume elasticity* in dynes per sq. cm. If the reciprocal of this last result be multiplied by 10^6, the result will be the *compression per atmosphere*. The numbers given in the table divided into the radius of the earth give what Thompson and Tait call the "lengths of the moduli of compression." See THOMPSON and TAIT, II, p. 225, § 689.

from homogeneity to heterogeneity would result in increased pressure in the interior, and in a decreased magnitude of the earth's volume and surface.

It is difficult to decide whether or not the minimum value of the eccentricity used above is too high to correspond with that uncertain date "the beginning of geological time." The rotation period of the heterogeneous spheroid would, probably, be shorter than for the homogeneous spheroid, and the shorter period may not be consistent with theories regarding the moon-earth couple. If we are required to assume a value of the eccentricity less than that used above, the changes in pressures I have given must be reduced. On the other hand, it must be remembered that there are causes at work which may augment the effects of a change in the internal pressure, and may even produce large results from what seem to be small causes. For example, if we suppose a contest in a given region in the interior between extreme heat on the one hand, and extreme pressure on the other hand, as to whether the material, or a single constituent of the material, will take on the crystalline form or not, we have a case in point. It may happen that a very slight increase in pressure may materially extend the zone in which crystallization may take place and thus result in a considerable increase in density; it is not impossible to believe that such a zone may exist in the region near the center, where pressures may be dominant on account of their enormous magnitude, and also in a region near the surface, where pressure may again be dominant owing to the lower temperature.

CHARLES S. SLICHTER.

THE GEOLOGICAL *VERSUS* THE PETROGRAPHICAL CLASSIFICATION OF IGNEOUS ROCKS.

THE rocks which make up the solid earth are of interest from a great many standpoints. A large part of geology is more or less directly concerned with them — as to their characteristics, their origin, their relationships in the mass of the earth, the changes in the rocks themselves, either metamorphism or decay, the mechanical destruction of rock masses, and structural changes in the earth dependent in many ways upon the characters of the rocks affected. From all of the points of view just indicated, and from still others, the geologist — often a specialist — has need for a nomenclature by which he may name the rocks as objects, and for various classifications expressing their observed relationships in different directions.

But while an adequate and expressive classification is a matter of great importance to many, it is commonly agreed that the systems of classification and nomenclature now in use are in a state of great confusion — of rapidly increasing confusion. To my mind the principal cause for this deplorable state of things is the lack of a clear conception of the natural relationship between *the systematic* classification of rocks, upon which their *specific* nomenclature must be based, and various *other*, *necessary* classifications of the same bodies. It seems that, while the multiform relations and affinities of rocks and their complex inner nature are more or less clearly understood, the futility of endeavoring to express all of these factors in one system of classification has not come sufficiently to recognition. It is my firm belief that no great progress in systematic petrography is possible until a more rational view of the relationship of that science to geology prevails among its devotees.

What is a rock? This question has often been found difficult to answer in satisfactory form. It is commonly said that rocks are the materials which make up the crust of the earth, and to distinguish them from minerals it is pointed out that a rock is a geological body — a geological unit. But it is the unit of material or substance, and must be clearly distinguished from the geological unit of form or mass. It is the substance of the geological body, but the two conceptions are not coextensive. Chemical and mineralogical composition and structure are the chief characters of rocks as concrete objects, and it is well known that neither a stratum of sedimentary rock, nor a dike of igneous rock, is necessarily of the same composition or structure throughout. The rock unit cannot be that of the geological body as long as this is true. The rock unit is simply that which the systematic scheme of rock classification finds most desirable and practicable.

It is universally recognized that rocks not only have many relationships, when viewed from the geological standpoint, but that as objects they are extremely complex and variable in character. Lossen has said that the property of transition in all directions is an essential characteristic of the rock. It is quite possible that some who have struggled with systematic problems may be inclined to define the rock as the most variable and indefinite thing in nature! Yet rocks must be classified and named according to some system, and the task is none the less interesting or important because of the difficulties involved. The best system, that most nearly natural and logical, most uniform and stable, must ultimately prevail.

I understand that branch of geology which is concerned with rocks in all their aspects to be petrology — a treatise on rocks — and the narrower systematic, descriptive science of rocks as concrete objects, the basis for their specific nomenclature, to be petrography. This usage has now become so current in this country that discussion seems unnecessary.

Let us pass in review some of the different aspects of rocks which must be considered by the geologist, and at the same time we shall outline the field embraced by *petrology*. (1) There is the rock itself — an object of variable and complex character.

Its constitution — chemical, mineralogical, structural, and physical — must be studied and described. The differences or similarities exhibited by rocks in these respects lead to classes, groups, and lesser divisions, and the expression of these relations to a system of classification and a specific nomenclature. (2) The genesis of rocks is a subject of many phases. The source of materials, the agencies of transportation, the conditions of rock formation, each of these problems must be investigated in detail. (3) The geological occurrence embraces the formal relationships of rock masses to the earth and to each other. (4) The genetic interrelationship of rock types is one of the most difficult questions to deal with. (5) The metamorphism, and (6) the decay or destruction of rocks, each embraces a wide field. To these may be added other important lines of study. It is thus evident that petrology embraces several lines of research, each in some degree independent, each also related to the others. The results may be primarily of value as applied to the general science of geology — the history of the earth, or to the uses of the systematic descriptive science — petrography.

There has long been much discussion as to the objects of rock classification. It has been considered, on the one hand, as a mere mechanism upon which to base a nomenclature, and at the other extreme of view as a means chiefly for the expression of geological relationships of rocks. Mr. A. W. Jackson has said that nomenclature (meaning specific nomenclature) must be wholly divorced from rock classification. But that arrangement of rocks, in accordance with which they are described and their specific names are applied, is in itself the most important of all classifications, *the* systematic classification. The question is as to the criteria to be applied to produce this system. Here there must be general agreement with Mr. Jackson [1] in the proposition, often enunciated before, that a uniform and stable nomenclature must be based on facts and laws, not on theories and hypothe-

[1] On the General Principles of the Nomenclature of the Massive Crystalline Rocks, by A. Wendell Jackson, Amer. Jour. Sci. (3), XXIV, 1882, p. 113.

ses. Other classifications may use theoretical criteria and they will often serve useful purposes, nay, they are indeed distinctly necessary to the progress of petrology, but such arrangements must always be considered as subject to revision.

The criteria available for the systematic classification of rocks, fall into two groups, viz., the properties of the rocks themselves as objects, and their relationships to each other and to the earth, which is made up of them. There has always been conflict of views as to the use of these criteria in establishing a systematic classification. In the early years of this century there were two opposing schools, one represented by the German geologist, Werner, who classified all objects in the mineral kingdom as geological bodies, the other best represented by the French mineralogist, Haüy, to whom rocks were purely mineral aggregates. For present purposes it is not essential, however interesting, to trace the development of systematic petrography, but it is worthy of note that the geological classification of rocks is still most strongly advocated in Germany, and the mineralogical classification is still most nearly realized in France.

But the early systems of petrography failed necessarily because based upon ignorance. The material constitution of rocks was but very imperfectly known, and their geological relations were in many respects matters of crude hypothesis. All systems to the present time have failed for these reasons, and the systems of today are not free from the weaknesses due to the application of theoretical criteria.

If we review the situation as regards our present knowledge of the properties of rocks as objects it does not seem too much to say that the development of chemistry and mineralogy, and the application of the microscope to the study of rocks, have given us an accurate insight into their chemical and mineralogical composition, their structure and texture, which cannot be essentially modified by future discoveries. These are the properties universally recognized as most applicable for subclassification.

With respect to the geological relationships of rocks the case is very different. Those rocks which are surface accumulations are so open to observation that we know many particulars of their origin—the sources of materials, the agencies by which the materials have been brought together, and the processes by which the rock has been made out of them. It is a curious fact that modern petrographers have done little toward formulating an adequate and logical classification and nomenclature for the rocks whose relationships are most evident, while they are continually extending, to an ever increasing degree of refinement, a systematic classification of igneous rocks upon foundations of theory or clear hypothesis. The fact that many criteria now used for the classification of igneous rocks are highly theoretical will hardly be questioned by anyone. From a philosophical standpoint it seems to me evident that such criteria cannot produce a stable system and must in consequence be rejected. A more detailed discussion of this question will follow.

Much has been said in recent years about the legitimate demands of geology upon systematic petrography. What are these demands? Clearly, both geology and petrography have certain reasonable demands to make, the one upon the other, but neither science has recognized its full natural rights, and hence has failed to state them properly. It is the unquestionable right of the geologist to demand of the petrographer a systematic classification of rocks, and a nomenclature expressing it, which shall be as natural and as stable as the controlling factors will allow. The petrographer must claim equal interest in such a system, and his logical counter demand is that he be allowed to construct that system through the application of the criteria best suited to produce the result desired. That is to say, he must reserve the right to reject hypotheses, theories, and even facts, if they are not adaptable.

It has often been said, from the time of the earliest classifications to the present, that rocks must be classified to express geological relationships. I believe that the geologist who today advances such a general proposition as a demand of geology upon systematic petrography is not in fact claiming his just rights. Rather, it must be said that he does not recognize his rights. He does not perceive the true relationship between geology—petrology—and petrography. Nor does the petrographer who accepts that proposition recognize his rights.

Defining petrology and petrography, as has been done, bearing in mind the complex and variable character of the rock and its manifold relationships, it seems to me that the petrographer should esteem it his duty to produce a systematic classification of rocks with a consistent nomenclature, which shall first of all possess stability. The nearer it approaches to a natural system the better, but the character of the rock precludes the hope of securing a fully natural system. The right of the petrographer under this principle is that he may apply the test of adaptability to each criterion offered. It may be said by some that the ultimate object of petrography must be to secure a thoroughly natural classification, and that when knowledge of the rock is extensive enough such a system will be possible. I believe that that position is incorrect, if, by a natural classification, is meant one expressing all the relationships of rocks. It is not because of ignorance that we cannot set up such a natural system for rocks. The nature of the rock is the cause of this inability, not ignorance concerning it.

The petrologist must classify rocks from every standpoint. He must apply many material facts, all of which cannot possibly be used in the systematic classification of petrography, so many sided is the rock. To illustrate this point, a sandstone is a rock which may be described as inorganic, derived, compound, clastic, stratified, sedimentary, aqueous, surficial, noncombustible, etc., and each of these terms expresses a criterion that has been used in some proposed systematic classification. The petrologist must also classify some rocks on bases of theory or hypothesis, with an expressive nomenclature. For the good of his science he should be able to change such classification and dependent nomenclature as required by advancing knowledge. This amounts to a revolution if the general classification must also be revised in each case. Is it not then a logical principle, for the good of all concerned, that the systematic classification of rocks, according to which their specific names are applied, must be based on their properties as objects, together with only such geological criteria as may be found adaptable, to the end that the system may be uniform, stable, and as natural as possible.

At this point I wish to digress for a moment and compare the task of the petrographer with that of the zoölogist, the systematic botanist or the mineralogist. From the beginnings of natural history, all natural objects have been subject to classification, at first on the most evident properties, and subsequently according to relationships. The modern zoölogist finds it possible to adopt nearly all of the general groups of animals early set up by the naturalist. Fishes, reptiles, birds, and other groups, needed only to be defined in scientific terms to bring general and scientific usage into harmony. The botanist has not been able to make his system correspond so closely to that of the naturalist. He has found that many natural groups of plants cannot be brought into his system, and he has wisely refrained from redefining the old names for those groups in such a way as to destroy their old and legitimate meaning. Thus trees (silvæ), shrubs, bushes, vines, evergreens, deciduous plants, and others, are not divisions of systematic botany, though recognized as useful and natural groups in the broader science of the vegetable kingdom. The properties and relationships of minerals may be nearly expressed in one system, but, as has been shown, rocks are of such manifold relationships that they defy a single system of classification to a much greater degree than plants.

If we now examine the schemes for the classification of rocks which have been current in the past few decades it appears that geological criteria have frequently been applied to produce the first divisions. It has been plain to all that rocks may be divided primarily into a few great classes on grounds either of geological occurrence or relationship, or of material properties. Each classification has its own justification, but the criteria to be applied in constructing a systematic scheme should plainly be those causally connected with the properties of the objects which are to be used in the further elaboration of the system. The geological agencies involved in the formation of the rock may be applied to produce rock classes differing in important material characters. This ground of classification has often been used, though not always logically carried out. It produces divisions both stable and natural. More or less distinctly the criterion of geological agency has been applied to form the classes called respectively the sedimentary, igneous and metamorphic rocks. Modern petrography has scarcely modified the old geological classification of sedimentary rocks, it has not yet anything which can be considered a system for metamorphic rocks, but it has elaborated a detailed scheme for igneous rocks, and it is now desired to review this system on the basis of the principles already presented.

Geological age has been commonly used as a criterion for the first subdivision of igneous rocks. It was originally applied in the belief that the older rocks differed in certain inherent and essential properties from younger ones. It was assumed that certain material characters were in some unexplained way governed by this geological factor, which thus became of prime classificatory value. But nearly all petrographers now perceive that assumption to have been unwarranted, and few would advocate a division of igneous rocks by age were it not for the double nomenclature in existence. It is difficult to agree upon the details of the simplification in this respect which all realize must eventually be effected.

It is in regard to the importance and applicability of geological form or place of occurrence and association of types as criteria for systematic classification that the greatest differences of opinion may be found among petrographers of today. The former of these factors, form or place of occurrence, has been and is still applied to the classification of igneous rocks on the ground that it is determinative of certain characters of rocks, and especially of structure, to a degree demanding recognition in this way. This usage is best represented by the well-known system of Prof. Rosenbusch by which massive or eruptive rocks are divided into three great classes: "Tiefengesteine," "Ganggesteine," and "Ergussgesteine." These terms are commonly translated into English as Deep-seated rocks, Dike rocks, and Effusive rocks. Let us examine this classification from the different standpoints of the systematic petrographer and the petrologist.

To begin with it is self-evident that these class names express geological occurrence. They represent natural divisions of the geologist, they were used by him long ago and must be used in future, to express natural relationships. The geologist has a logical and practical claim upon these terms which cannot be denied. The question then is, can this geological classification be applied to the uses of systematic petrography, producing natural classes of rocks, a result which would be of great benefit to all concerned. I believe that it cannot be so used.

The system of Professor Rosenbusch is avowedly intended to meet the legitimate demands of geology upon his systematic science, as formulated by Lossen, to the effect that geological relations of rocks must be recognized as petrographical relations.[1] But while aspiring to meet the conceded demands thus expressed Rosenbusch has so redefined each of these grand divisions that it does not include all rocks belonging in it upon the criterion most clearly expressed in the name, the criterion the geologist must apply, and does include rocks that cannot logically be placed there. To illustrate by the most striking instance, the Dike rocks of Rosenbusch are not rocks occurring in dikes, which must be the geologist's definition, but rocks of as yet hypothetical derivative relation to certain other rocks. This class includes a small part of the rocks actually occurring in dikes and many not so occurring. Similarly the Deep-seated rocks of Rosenbusch are not necessarily abysmal. They appear in dikes and other intrusive bodies near the surface and even in some effusive masses. The Effusive rocks of this system occur in many intrusive masses and in the peripheries of deep-seated

[1] Über die Anforderungen der Geologie an die petrographische Systematik. Jahrbuch der K. pr. geol. Landesanstalt, 1883, p. 486.

bodies. That the above statements are true is abundantly admitted by Professor Rosenbusch in the pages of his "Mikroskopische Physiographie der massigen Gesteine."[1]

The classes of igneous rocks established by Rosenbusch upon the criterion of geological occurrence are not those of the geologist. But it is well understood by all familiar with the subject that an assumed relation between geological occurrence and structure of igneous rocks lies at the basis of Rosenbusch's inconsequent definitions of the three classes under discussion. In fact, the petrologist studying the genesis of igneous rock structures knows that they result from a complicated set of chemical and physical conditions attendant upon the consolidation of molten magmas. These conditions are as yet only partially understood. Pressure, absolute temperature, rate of cooling, the chemical changes in the fluid residue owing to fractional crystallization, the influence of so-called mineralizing agents, and several other factors, are recognized, but their relative importance is yet a matter of theory or hypothesis. A predominating influence was not long ago assigned to pressure, measured by distance from the earth's surface. But it is now known that that condition is in itself of little importance, within the zone of the earth's crust of which we have definite knowledge. It is also known that the conditions of consolidation are not controlled by either geological form or place of occurrence, to an extent capable of definite statement. The petrologist must recognize that while the typical granular structure is most common in abysmal igneous masses it may develop and is often found in the intrusive bodies of the intermediate zones of the crust and in surface masses. Nor has size of the molten body a determining influence. Neither are the porphyritic or fluidal structures dependent upon the geological form or place of occurrence of rocks exhibiting them.

Since the petrologist must inevitably apply the geological

[1] The natural limitations of the present discussion prevent an analysis of the considerations which led the German master to propose such a classification, but a review of the Rosenbusch system upon the principles here presented is now in preparation and will soon appear in this JOURNAL.

criteria of form and place of occurrence for the classification of igneous rocks into certain logical and natural groups, and has for this purpose a consistent language and mode of expression, he must surely demand of the systematic petrographer that these criteria shall not be used to produce another classification with other definitions of the same terms. Such a course produces confusion for which there can be no justification. It is to me utterly incomprehensible how the appropriation and redefinition of the geologist's terms and nomenclature can have been carried through as in the Rosenbusch system under the idea that thereby the science of geology would be benefited. And where is the science of petrography benefited by the formation of systematic groups which are confessedly unnatural and wholly unnecessary?

The petrologist must express the facts of the relationship between rock structure and geological occurrence, as between structure and other factors, to the best of his knowledge at any given time. It is not to his advantage to have this relation, always to be a matter of interpretation or theory to some degree, expressed in the systematic scheme. Nor can it be to the advantage of the system, for it will be a cause of instability.

The genetic interrelationships of igneous rocks, which most petrologists believe to be the result of what is called magmatic differentiation, are most important, but are clearly of hypothetical nature, and must remain at best matters of theory as long as the origin of the earth itself is veiled in mystery. It seems to me utterly impossible to admit such factors into the petrographic system. But it is the tendency of several leading investigators of today, notably of Rosenbusch and Brögger, to make these theoretical relationships more and more prominent in systematic classification, and from the considerations above presented I wish to make most earnest protest against this tendency as really contrary to the best interests of both geology and petrography. In thus protesting, I must not be understood as failing to appreciate the great advance in our knowledge of the origin of igneous rock varieties and of their structures, and of the genetic relationships of types which has come within the past few years largely as a result of a promulgation of the theoretical ideas lying back of the systematic scheme advocated by Rosenbusch. One may well deny the desirability of the Dike rock group of Rosenbusch and be at the same time an ardent advocate of the theories upon which the group was established, and which have little connection with the fact of geological occurrence expressed in the name. Classifications of rocks, expressing working hypotheses as to their genesis, are necessary and may be set up at will if disconnected with the systematic classification. A stable nomenclature for rocks as objects will facilitate rather than hinder development of theoretical science.

I believe, then, that geological occurrence is not a practicable criterion for systematic classification of igneous rocks, and that it has been applied to that purpose through a misunderstanding of the true position of systematic petrography to the broader science of rocks. The petrographer has for many years failed to perceive, or, at least, to acknowledge, the right of the geologist to any special nomenclature of rocks. He has taken the time-honored terms of the geologist, redefined them to suit his own special purposes, until the geologist who is not a petrographer is almost afraid to use the simplest and most plainly denotive terms lest he be denounced as unscientific. But I maintain that it is the petrographer who has been unscientific, when he has misappropriated the natural nomenclature of the geologist, and when he has defined structural terms to express a genetic theory, or has applied them to certain rocks only out of all those possessing the structures in question. The definition of the granular structure as one having a certain mode of origin, instead of stating what the structure really is; the appropriation of *granulite* and *granite* for certain granular rocks, leaving no appropriate name for all rocks of that structure; the misuse of *porphyry* in analogous ways,—these are illustrations of thoroughly undesirable precision of definition, undesirable because at the expense of the geologist who has a prior and logical claim to these terms and needs them in their original senses.

RÉSUMÉ.—Rocks are too complex in their characters and have too many and too varied geological relationships to permit of one systematic classification expressing all their properties and relationships. A primary division on geological grounds may be carried through, producing classes of different characters, and such a division is universally advocated.

Since all the geological relationships cannot possibly be used in one system, it appears that a distinction must be made between that classification by which rocks are grouped for purposes of description and naming as concrete objects, and all other classifications. The former may be called the systematic classification, and I consider petrography to be the science presenting and applying that system to the description and naming of rocks. The broader science of petrology, using the nomenclature of petrography for specific purposes, must arrange rocks in as many other ways as are desirable to express their characters or relationships not introduced into the systematic scheme, and for the expression of these other arrangements a separate terminology is essential. It must not be appropriated under redefinition by the petrographer.

The material properties of igneous rocks afford ample criteria for establishing a systematic classification, and the use of geological relations is unnecessary. Since the geological factors of age, or of form or place of occurrence are not directly causes of the properties used in classification, they cannot be applied to produce coördinate groups. The attempts to thus apply them have been unfortunate. The justification of these attempts has been the belief that geology demanded that geological relations be recognized as petrographical relations. In the view above set forth this belief is illogical, and has resulted in injury both to geology and systematic petrography.

The impossibility of setting up an all-embracing natural classification of igneous rocks is not due to ignorance. It comes from the nature of the rock. The more we know the less shall we be able to include all relations in one classification.

WHITMAN CROSS.

ON ROCK CLASSIFICATION.

"To CLASS rightly — to put in the same group things which are of essentially the same natures, and in other groups things of natures essentially different — is the fundamental condition to right guidance of actions." These words of Herbert Spencer[1] may well form the introduction to this discussion, for they not only declare the importance of right classification, but state clearly in what it consists. It is because of the possibility of losing sight of its actual character in the approaching conflict over the reformation of rock nomenclature, that emphasis is laid at this time upon what seems to the writer to be the true character of rock classification. According to high authority[2] classification is "the act of forming a class or of dividing into classes." And further, a class is defined as "a number of objects distinguished by common characters from all others, a collection capable of a general definition."

To class rocks rightly would be to put in the same group or class those which are of essentially the same natures, or which may be distinguished by common characters from all others, and which may be capable of a general definition. This leads at once to a consideration of the nature of rocks and of the characters by which they may be distinguished from one another and which may be employed in their definition.

Nature and characteristics of rocks. — The origin or formation of rocks affects their nature to so great an extent, that it has been made a first basis for their subdivision, resulting in three categories: eruptive, sedimentary, and metamorphic. These, however, do not occupy the same position in the order of formation, but may be considered in one case as essentially primary, and in the others as secondary or derivative. The character of the rocks of these three categories, while possessing some points

[1] Man vs. State, p. 5.

[2] The Century Dictionary.

of similarity, are, nevertheless, so diverse in others, and the laws of their relationships are so unlike, that it is advisable to consider them separately. The present discussion will be confined to rocks of the first category — that is, eruptive or igneous rocks.

The most distinctive features of any igneous rock are those inherent in the mass, namely, the chemical composition, the mineral composition, and the manner in which the constituents are grouped together — the texture and physical aspect of the rock.[1] Other characters of quite as essential natures are, however, less distinctive; such are the form or dimensions of the body of the rock and its formal relations to adjacent rock masses; that is, its body as a geological unit and its occurrence or habitat, and finally its connection or relation to other igneous rocks — its association — and hence its origin.

These two groups of characters are of different orders. The first are clearly material, having to do with the chemical elements and the minerals making the substance of a rock. The second are modal, having to do with forms and relationships among rocks. Failure to recognize this difference has led to confusion of ideas and of methods in classification and in didactic treatment. The rapid development of speculation along the lines of rock genesis in conjunction with the accumulation of many facts regarding the composition, occurrence, and association of igneous rocks, has prevented the proper consideration of these phases of the science apart from one another.

It seems necessary to call attention to a difference which in this science, at least, must always exist between a classification of the material under investigation — the rocks — and a treatment for purposes of instruction or of discussion of the whole subject of petrology, or of the rocks of any petrographical province.

It may be thought at this point that the writer's conception of a classification is too narrow and restricted, and that a system

[1] Cf. Michel-Lévy, A., Structures et Classification des Roches Eruptives, Paris, 1889, p. 34.

of classification may be found, such that the two objects may be accomplished at one and the same time. It is the purpose of this paper to show that this is not consistent with the nature of the case, and that a classification of rocks and the didactic treatment of them cannot be based on the same method of procedure. In order to do this it will be necessary to consider: (1) the character of the constituents of individual rocks, both chemical and mineral; (2) the results of a study of the chemical composition of all kinds of igneous rocks; (3) the occurrence of these constituents in any rock as a result of processes of differentiation, according to generally accepted theories; (4) the chemical relations of series of rocks genetically connected; (5) the nature of a rock-body or geological unit; (6) the nature of rock-association, as in petrographical provinces.

The character of the constituents of igneous rocks both chemical and mineral.—The same chemical elements occur as constituents of nearly all igneous rocks. In the great majority of those analyzed oxygen, silicon, aluminium, iron, magnesium, calcium, sodium, and potassium occur in measurable proportions; while other elements, as phosphorus, titanium, manganese, barium, strontium, chromium, nickel, cobalt, lithium, zirconium occur in determinable amounts in many rocks, and in traces in others. In many cases their presence has not been sought. In numerous cases other elements are present in very minute quantities as shown by the frequent occurrence of alla nite containing the rare elements cerium, lanthanum, didimium.[1] Neglecting for the present elements commonly occurring in very small amounts, the eight elements first named are those which chiefly characterize igneous rocks. In very few cases one or two of these may be absent or in traces only, but in almost every case they are all present. Chemical differences among these rocks consist in the proportions in which all of these elements exist in each case. Hence a classification of igneous rocks

[1] CLARKE, F. W., On the Relative Abundance of the Chemical Elements, Bull. U. S. Geol. Survey, No. 78, 1891, p. 34. Also Bull. U. S. Geol. Survey, No. 148, 1897. See also ZIRKEL, F., Lehrbuch d. Petrographie, 2d ed., 1893, Vol. I, p. 648.

upon a chemical basis in nearly every instance is the grouping together of rocks that have like proportions of the same chemical elements.

The mineral components of igneous rocks are somewhat less constant in character than the chemical elements. Rocks occur that have distinctly different mineral components such as a granite with quartz, orthoclase and biotite, and a gabbro with labradorite, augite and hypersthene. But others occur having the same kinds of minerals in quite different proportions, such as a granite with much quartz and orthoclase and little biotite, and a syenite with much orthoclase and little quartz and biotite. Neglecting for the present the rarer or least abundant minerals that are found in igneous rocks, the characteristic ones are: quartz, feldspar, leucite, nephelite, sodalites, analcite, micas, pyroxenes, amphiboles, olivine, magnetite. Of these only one possesses a fixed composition, that is, quartz. Magnetite may contain a variable amount of titanium. Leucite, nephelite, and analcite may vary in the relative proportions of potassium and sodium present. Olivines differ in the proportions of iron and magnesium. While the others represent series of minerals grouped together on crystallographic grounds, but varying often widely in chemical composition. The feldspars embrace polysilicates with variable amounts of potassium and sodium, besides compounds assumed to consist of polysilicate and orthosilicate, varying in alkali metals, calcium and silicon. Micas, pyroxenes, and amphiboles present groups which are chemically still more variable. The chief mineral components of rocks then are not definite chemical compounds, but are substances that may vary within limits according to the proportions of the chemical elements in the magma from which the rock solidified. Moreover the same chemical elements appear in several of these minerals: oxygen in all, silicon in all but one, aluminium and the alkali metals in five, iron and magnesium in four, calcium in three and so on. Hence a change in the relative proportions of the chemical elements in a magma may affect nearly all of the mineral constituents.

The results of a study of the chemical composition of all kinds of igneous rocks.—In attempting a study of the chemical composition of all kinds of igneous rocks it was found necessary at the outset to devise some means by which the variations in the chemical analyses could be compared with one another graphically or by tabulation. It was also thought desirable to consider the chemical composition in its relations to the mineral composition, as far as possible. Further it was necessary to reduce the number of variable quantities to be treated in any one scheme. And for convenience and economy of labor the oxides of the metals were employed instead of the metals themselves, in all cases their molecular proportions[1] being used and not their percentages by weight.

In order to reach a basis for the correlation of the minerals and the chemical compositions of the rocks, the minerals may be divided into two groups, one embracing quartz, feldspars and the feldspathoid minerals: leucite, nephelite, sodalite, and analcite; all except quartz containing aluminium and the alkali metals or calcium, and being free from iron and magnesium. The other group contains the amphiboles, pyroxenes, micas, olivine, magnetite; all excepting magnetite containing magnesium as well as iron. Muscovite may be classed with the first group, but grades into biotite and may also be classed with the second group. The first group includes orthosilicates of aluminium and sodium, metasilicates of aluminium, sodium, and potassium, polysilicates of aluminium, sodium, and potassium, and free silica. In each case the ratio between alumina and the alkalis is a constant 1:1; except in the sodalites, in which soda is somewhat in excess of alumina. Calcium combines with aluminium in an orthosilicate molecule in which the ratio between the alumina and lime is also 1:1. This anorthite molecule combines with albite molecules so as to form a continuous series of compounds from orthosilicate to polysilicate. A consideration of the occurrence of these minerals in igneous rocks shows that quartz

[1] Found by dividing the proportionate weights of each oxide by its molecular weight.

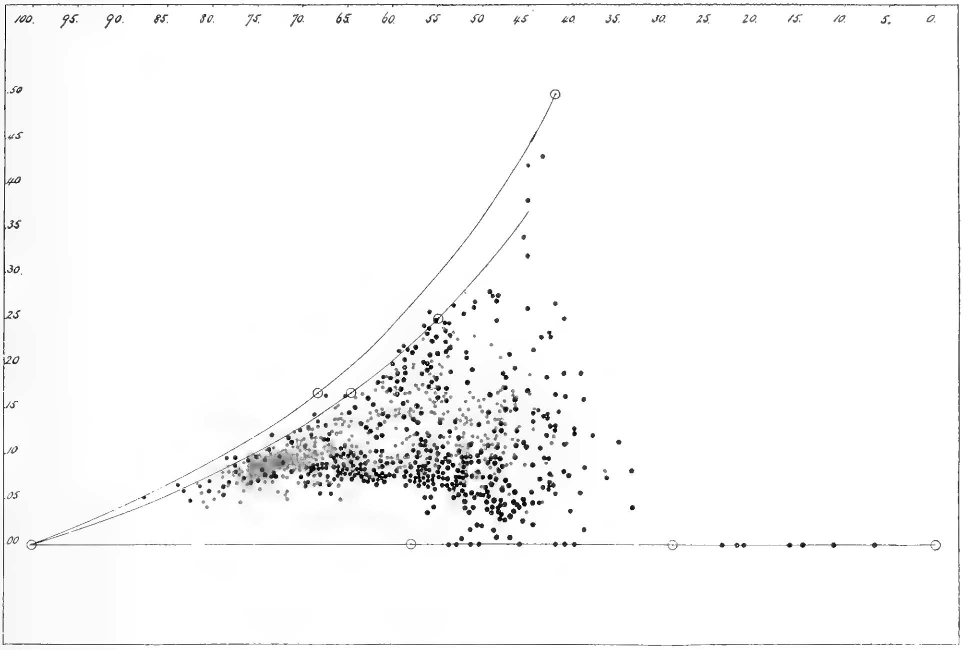
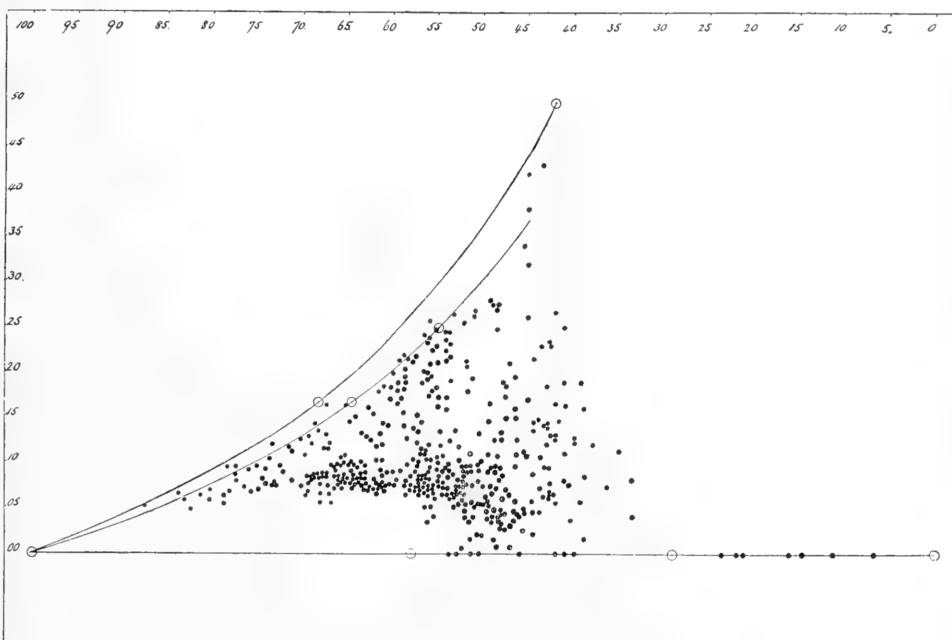


DIAGRAM 1.



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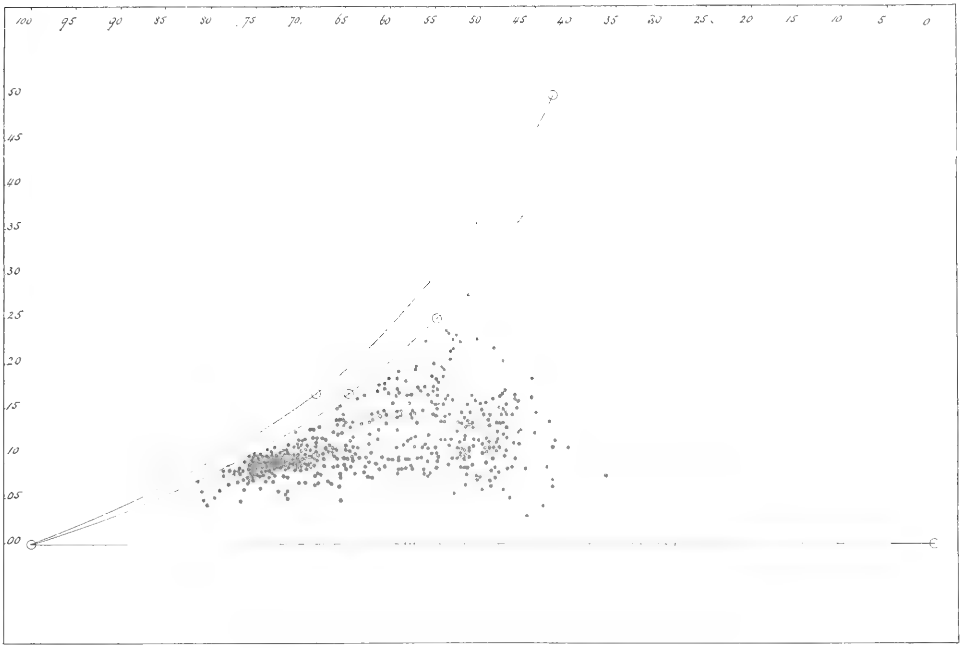

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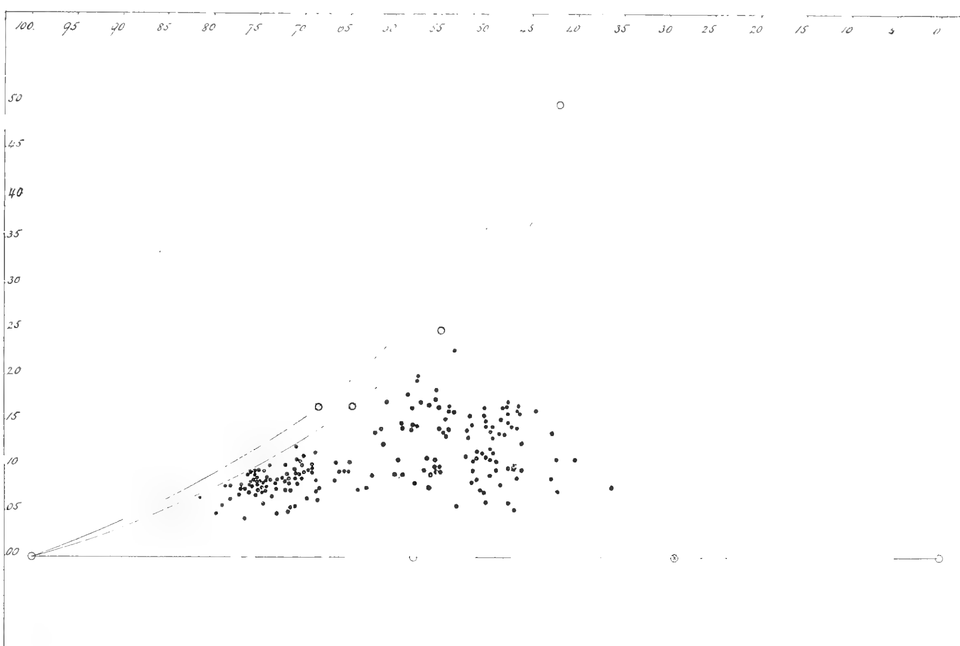

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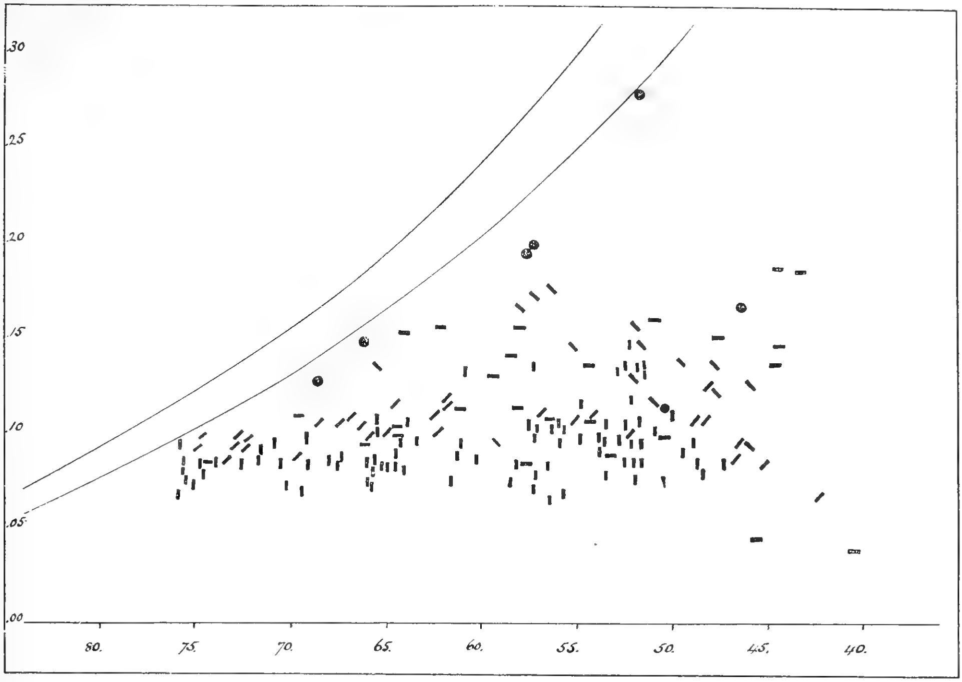

Yellowstone National Park.
Crazy Mountains, Mont.
Little Belt Mountains, Mont.
Highwood Mountains, Mont.
Bearpaw Mountains, Mont.

Diagram 5.

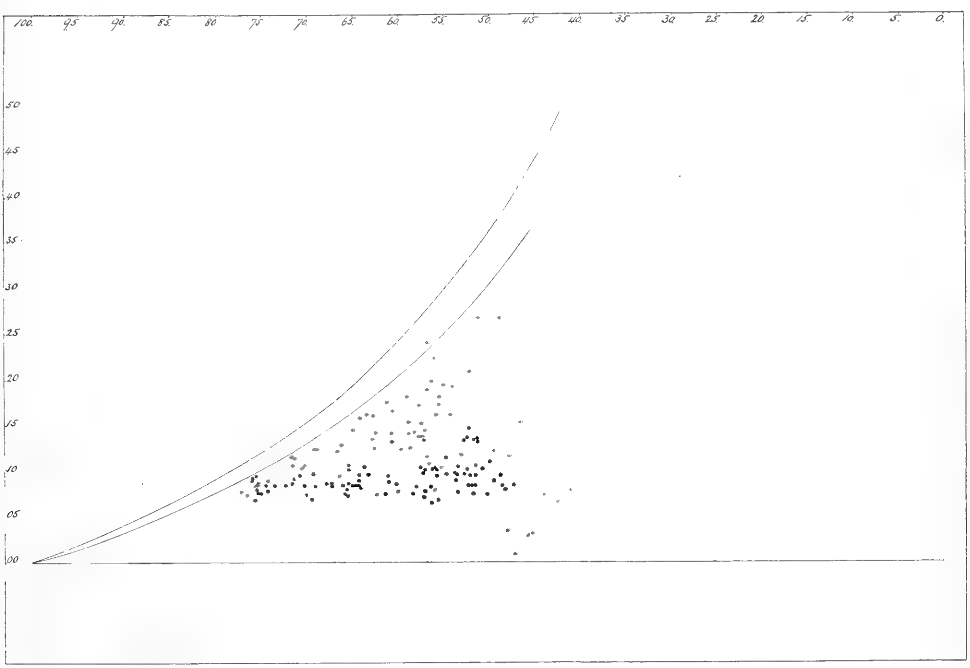

Diagram 6.

does not occur with the alkali metasilicate or orthosilicate feldspathoid minerals. And these are found in rocks comparatively low in silica, the orthosilicate being most abundant in the least siliceous rocks. But quartz is found in variable proportions with polysilicate feldspars, usually in rocks high in silica. So that it appears to be a law that so far as the alkali-aluminous silicates are concerned the highest silicate forms which is possible with the available silica in the magma. Thus a close relationship exists between the amount of silica in the magma and the development of these ortho-, meta-, and polysilicates; as does also, quite naturally, the presence of free silica or quartz. No such evident relationship has as yet been discovered between the occurrence of the ferromagnesian minerals and the amount of silica in the magma.

Investigation also reveals the law, apparently of quite general application that to a great extent the alkalis in a magma control the alumina in such a manner as to compel it to enter a feldspathic mineral if possible,[1] so that a reasonable estimate of the amount of feldspathic constituents in a rock may be formed by reckoning the alkalis and alumina together with the available silica as alkali-feldspathic constituents. And while it is well known that the alkalis may enter abundantly into micas and to a less extent into amphiboles and pyroxenes, it seems to be the rule that they do not enter the two latter minerals to any considerable extent unless the alumina present in the magma is insufficient to form feldspathic minerals. The case of biotite is different and does not conform to the rule, necessitating some modification of it.

It seems true also that in a great majority of cases aluminium does not combine with calcium to form anorthite molecules unless there is an excess of alumina over the alkalis in the magma. Exceptions to this rule, of course, occur, but its appli-

[1] This assumption which has been used by the writer in his lectures as a working hypothesis for several years has also been advocated recently by MICHEL-LÉVY in his paper entitled Classification des Magmas des Roches Éruptives, Bull. de la Soc. Géol. de France, 3d series, Vol. XXV, pp. 342–343, Paris, 1897.

cation appears to be more general than was at first suspected; and by means of both laws a crude approximation to the composition of the feldspathic constituents in any rock may be obtained.

With regard to the occurrence of the minerals of the second group, it is a general law that they are most abundant in proportion to the diminution of silica and of the feldspathic minerals, so that an expression of the variations in these will also express inverse variations in the ferromagnesian minerals. To a very considerable extent the occurrence of the orthosilicate, olivine, and of the metasilicate, hypersthene, depends on the available silica in the magma, the former occurring in rocks with lower silica.

From these considerations it is evident that a comparison of the chemical composition of rocks may be undertaken so as to bring out the relations between the alkalis and the silica, and between these components and the feldspathic constituents, and that indirectly some notion may be had of the relations of the ferromagnesian constituents. Since two coördinates or variables only can be employed in a plane diagram or table, and a third involves a representation in three dimensions, or by some other device, it is necessary to reduce the factors to at least three. Those selected for the present investigation are, first, the silica on account of its important rôle in conditioning the character of the alkali-feldspathic constituents; second, the molecular ratio between the alkalis, soda, and potash, taken together, and the silica $\left(\frac{Na_2O + K_2O}{SiO_2}\right)$, for this corresponds to the relative proportions of orthosilicate, metasilicate, and polysilicate feldspar and quartz. The amount of silica in each case was made the abscissa and the alkali-silica ratio the ordinate, and since these quantities are not of the same kind, it is not necessary that the scale of parts should be the same for both. For convenience the amounts of silica were plotted directly from the percentages in each analysis. By this means it is possible to investigate the distribution of all the rock analyses studied with reference to these two factors. A third factor may be expressed by inserting a number at the locus in the diagram of each rock analysis which shall indicate some other molecular ratio, such as that of the approximate feldspar

$$\left(\frac{Al_2O_3-(Na_2O+K_2O)}{2\,(Na_2O+K_2O)}\right)$$

Or in another case the molecular ratio between the ferrous oxide, magnesia, and the lime not calculated with the anorthite molecule, and the silica.

$$\left(\frac{FeO+MgO+CaO-(Al_2O_3-[Na_2O+K_2O])}{SiO_2}\right)$$

The comparison by the method just indicated of 928 chemical analyses of igneous rocks has given rise to the accompanying diagrams. The analyses were selected with care in order to avoid those of much altered rocks, or those likely to be untrustworthy. The greater part have been made by chemists of the U. S. Geological Survey, which has furnished the most considerable contribution to the knowledge of the chemistry of rocks ever made by any organization. The analyses include those of all known kinds of igneous rocks that have been analyzed, so far as the writer has encountered them.[1]

Diagram 1 shows the distribution of all the analyses, the black spots representing those in which soda is more than twice the potash molecularly; the red spots those in which it is less than twice the potash. Diagram 2 is for all those in which the molecular ratio of soda to potash is greater than 2, — $\frac{Na_2O}{K_2O} > 2$. Diagram 3 is for all those in which this ratio is less than 2, — $\frac{Na_2O}{K_2O} < 2$. Diagram 4 is for those analyses in which this ratio is equal to or less than 1, — $\frac{Na_2O}{K_2O} \leq 1$. One of

[1] The analyses have been taken from the following sources: Analyses of Rocks and Analytical Methods, Bull. 148, U. S. Geol. Survey, 1897. Analyses in papers published by PIRSSON and WEED. ROTH's tables of rock analyses. BRÖGGER's publications, and many others.

the most notable features of Diagram 1, is the evident limitation of the range of alkali-ratios along the curved lines. These lines were suggested by the distribution of analyses in the diagram and represent in one case, the upper line, the possible range of analyses for rocks consisting wholly of silica, alumina, and soda, the two last elements being always in the proportion of 1 : 1 ; corresponding to nephelite at one extreme, succeeded by a mixture of nephelite and a possible metasilicate of these bases, or of nephelite and albite, and of albite and quartz, and finally of quartz alone. In the case of the lower line the curve corresponds to a possible range of analyses for rocks consisting of silica, alumina, and potash, the latter being in the proportion of 1 : 1. The mineral range would be from pure quartz, through a mixture of quartz and potash feldspar, to one of potash feldspar and leucite, to a possible orthosilicate of aluminium and potassium, corresponding to a potassium nephelite. In not a single instance is the sodium-aluminium limit transgressed, and only a few cases occur beyond the potassium limit. The rocks actually consist of the minerals just named. A nearly pure nephelite rock exists as urtite from the Kola peninsula,[1] and as portions of the nephelite-syenite of Dungannon township, Canada, described by Professor F. D. Adams.[2] A nearly pure albite rock has been found in California, by Mr. H. W. Turner.[3]

The fact that these limits are so closely approached, but never transgressed, is a clear indication that the alkalis do not exist in greater proportions than may satisfy this series of ortho-, meta- and polysilicate molecules. There are instances, however, in which part of the requisite alumina is replaced by ferric oxide.[4] There are a few cases in the neighborhood of

[1] RAMSAY, W.. Urtit, ein basisches Endglied der Augitsyenit-Nephelinsyenit-Serie, Geol. Fören. i Stockholm Förhandl,— Bd. 18, Häft 6, 1896, p. 459.

[2] ADAMS, F. D., On the Occurrence of a Large Area of Nepheline-Syenite in the Township of Dungannon, Ontario, Am. Jour. Sci., Vol. XLVIII, July 1894, p. 10.

[3] Further Contributions to the Geology of the Sierra Nevada, 17th Ann. Rep. U. S. Geol. Survey, Washington, 1896, p. 728.

[4] The most marked exception to this rule is the group of rocks from Leucite Hills, Wyo., described by CROSS, Igneous Rocks of the Leucite Hills and Pilot Butte, Wyoming, Am. Jour. Sci., Vol. IV, 1897, pp. 115–141.

these limits in which alkalis are in excess of the alumina, when sodalite minerals abound;[1] and others in which alumina is in excess, when muscovite forms. From the foregoing it appears that if differentiation has taken place to produce these magmas there has been no considerable accumulation of alkalis independently of all other constituents. And from the approach to the pure nephelite molecules by sodium magmas, and from the limitations of the potassium magmas in the neighborhood of the leucite molecule, there is the strongest indication that the differentiation of the magmas affected molecules more complex than simple oxides of potassium and sodium, and probably as complex as silicates of aluminium and sodium or potassium, corresponding to known mineral molecules. However, as already stated, there are proofs deducible from the laws of crystallization that the molecules in molten magmas are not stable or fixed, and the aluminium and potassium, for example, may enter orthoclase, leucite or biotite according to circumstances in the form of ortho-, meta- or polysilicate.[2]

In the direction of the maximum limit of silica, there are rocks consisting of alkali-feldspars and abundant quartz, which may grade into pure quartz, as suggested by Lehmann[3] and Howitt;[4] certain quartz veins being eruptive and extreme forms of aplitic intrusions. Thus the oxide molecule, SiO_2 appears to be capable of separation by processes of differentiation from other silicate molecules. If analyses had been made from these rocks, the diagrams would have shown a distribution of analyses as far as 100 per cent. of silica. The minimum limit of silica should occur in connection with differentiation products free

[1] WEED, W. H. and PIRSSON, L. V., The Bearpaw Mountains of Montana, Am. Jour. Sci., Vol. II, No. 9, 1896, p. 197.

[2] IDDINGS, J. P., The Origin of Igneous Rocks, Bull. Phil. Soc., Washington, Vol. XII, 1892, p. 176.

[3] Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, etc., Bonn., 1884, p. 55.

[4] Notes on the Area of Intrusive Rocks at Dargo, Trans. Royal Soc., Victoria, 1887, Vol. XIII, p. 152. Also Notes on Certain Metamorphic and Plutonic Rocks at Omeo, p. 10.

from silicate minerals, such as certain iron ores[1] whose analyses occur at the extreme lower right hand corner of Diagram 1. From these it is evident that molecules of iron oxides may separate by differentiation from silicate molecules. The maximum limit for soda will be when the soda-silica ratio is 0.5, that is when NaO_2 =21.75 per cent. and SiO_2 = 42.10 per cent. The maximum limit for potash will be when the potash-silica ratio is 0.25, that is when K_2O=21.51 per cent. and SiO_2 =54.92 per cent. Both alkalis sink to a minimum of zero in certain kinds of peridotites, pyroxenites, and in certain eruptive iron ores. They may disappear in anorthosite composed of pure anorthite.

The limit of distribution of analyses toward low silica appears to be a line which would correspond to a variable mixture of the lowest alkali-alumina silicate — nephelite for soda magmas, and leucite for potash-magmas — and the least siliceous ferromagnesian silicate, fayalite. This limit will probably be modified when series of rocks are analyzed grading from gabbros to the iron ores. The range of variations in the proportions of iron oxides, magnesia, lime and alumina, does not appear in these diagrams.

In this connection it may be pointed out that the variations in all of the chemical constituents, other than silica, must increase in proportion as silica decreases. When 75 per cent. of the magmas is silica, only 25 per cent. remains for other constituents, but when there is only 40 per cent. of silica, 60 per cent. must consist of other compounds. It is known that rocks high in silica contain much more alumina and alkalis than other constituents, hence the variation in these other constituents cannot be great. The greatest variation occurs when part of the alumina is replaced by ferric oxide. But in rocks low in silica there is no general law controlling the other constituents, which may, therefore, vary widely in different rocks. Consequently the number of different kinds of rocks possible

[1] Vogt, J. H. L., Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivmagmata, Zeitschr. für prakt. Geol., Berlin, 1893, Jan., Apr.

for any given percentage of silica is much greater the lower the percentage of silica.

Diagram 1 shows that within the limitations above mentioned there are nearly all possible transitions in relative proportions of alkalis and silica, and the same is true for other constituents. Diagrams 2, 3 and 4 show that the range of alkali variation is greatest for rocks in which the ratio of the soda to the potash is greater than 2, and least for those in which it is less than 1. That is, it is greatest for distinctly sodic rocks and least for those very rich in potash.

While there is a clustering of analyses in the parts of the diagrams corresponding to lower alkali-silica ratios, there are no loci of specially marked aggregation, except toward the most siliceous end of the more potassic groups, and no such clustering as to suggest natural subdivisions of the analyses on any chemical basis. A chemical subdivision must be an arbitrary one, making breaks in continuous series. Comparison of Diagrams 2, 3 and 4 shows that the most siliceous rocks are generally richer in potash than in soda, also that the rocks in which alkalis decrease to nearly zero contain much more soda than potash. Those parts of the diagrams in which few analyses occur will undoubtedly be filled up as more rocks are analyzed.

It is to be noted that analyses occurring in close proximity to one another in these diagrams, and nearly alike in percentages of silica and alkalis, may in some cases differ more or less widely in other respects, so as to belong properly to different classes of rocks. They are by this method of comparison the more strongly contrasted and their essential differences more clearly recognized. This method of comparison brings closely together rocks agreeing in chemical composition, but often differing in mineral composition and physical characters, and having quite different names, and in this way emphasizes the necessity for improved definitions of names already in use and for the creation of a systematic nomenclature.

The occurrence of these constituents in any rock as a result of proc-

esses of differentiation according to generally accepted theories.—A study of the crystallization of rocks has shown[1] that different minerals and combinations of minerals may form from magmas chemically alike, according to physical conditions influencing the crystallization, proving that the chemical constituents in the molten magma do not exist, wholly at least, in definite or fixed combinations or molecules corresponding to distinct mineral molecules. Moreover, if the molecular character of a molten magma shortly before it solidifies is not fixed, but is flexible, its molecular character at an earlier period, when differentiation may take place is undoubtedly flexible or unstable, and probably to a greater degree. This is indicated by the variability in the composition of minerals of the same group, such as pyroxenes, feldspars, etc., in rocks genetically related, and assumed to have been derived by differentiation from a common parent magma. Thus in genetically related rocks the feldspars may range from those high in potash to those high in sodium and to others low in alkali metals and high in calcium; pyroxenes may range from those rich in calcium and magnesium, with little iron and aluminium, to others richer in the latter elements and to those rich in sodium and iron. Several members of either of these mineral series or groups may occur together in one rock, and may occur in varying proportions in different rocks.

The facts known regarding the mineral composition of genetically related rocks, to which the theory of differentiation has been made to correspond, are that the proportions of the component minerals, as well as their chemical compositions vary not only with different bodies of rocks, but not infrequently with one rock-body. Furthermore, this variation is in many cases gradual, with known transitions, while in other instances differences of composition are marked, and transitional forms have not yet been found. Consequently from the theory of differentiation

[1] ROTH, J., Gesteinsanalysen in tabellarischer Übersicht, etc., Berlin, 1861, p. 21.

IDDINGS, J. P., Bull. Phil. Soc. Washington, 1892, Vol. II, p. 217. Also 12th Ann. Rep. U. S. Geol. Survey, Washington, 1892, p. 659.

LINDGREN, W., A Sodalite-Syenite and other Rocks from Montana, Am. Jour. Sci., Vol. XLV, 1893, p. 297.

rocks with variable proportions of the mineral constituents are to be expected to be the rule rather than the exception And when all igneous rocks are taken into consideration all possible combinations of mineral proportions may be anticipated.

The chemical relations of series of rocks genetically connected.—The chemical characters of genetic series of rocks has been considered their most distinguishing and essential characteristic—the one quality that established their consanguinity.[1] It might be thought then that such a feature could be employed as a means of classifying igneous rocks in groups corresponding to genetic series. Careful consideration of the actual nature of this chemical character will lead to the opposite conclusion.

Certain genetic groups of rocks are distinguished by relatively high alkalis, in one instance largely potash, in another largely soda. Other genetic groups are characterized by relatively low alkalis. But even in these series not every rock contains the same high or low alkali ratio as the preponderating varieties. In fact there are often members of the series which are chemically quite different from the greater number of rocks belonging to the series. In some genetic series it is the ratio between the potash and soda that is characteristic, the total alkalis being large in some rocks of the series and low in others. But here again the ratio is never constant, and the variation may be quite large.[2] In no one genetic series yet described has any single chemical character been found to be persistent throughout the series. Nevertheless the transitions between the rocks of the series are sufficiently pronounced to leave no reasonable doubt that the rocks in question have been derived from

[1] ROSENBUSCH, H., Ueber die chemischen Beziehungen der Eruptivgesteine, Min. u. petr. Mitth., Vienna 1889, Vol. II, pp. 144–178.

BRÖGGER, W. C., Die Mineralien der Syenitpegmatitgänge der Südnorwegischen augit- und nephelinsyenite, Zeitscht. für Kryst. u. Min., Leipzig, 1890, Vol. XVI.

IDDINGS, J. P., Origin of Igneous Rocks, Bull. Phil. Soc. Washington, 1892, Vol. XII, p. 135.

[2] BRÖGGER, W. C., Die Eruptivgesteine des Kristianiagebietes. I. Die Gesteine der Grorudit-Tinguait-Serie, Christiania, 1894, 165.

WEED, W. H. and PIRSSON, L. V., Geology of Castle Mountain Mining District, Montana, Bull. U. S. Geol. Survey, No. 139, 1896, p. 137.

some parent magma by some process of chemico-physical separation or differentiation.

Besides genetic series that are chemically quite distinct from one another there are others much less so, and others that resemble one another closely. Petrographical provinces are in some cases strongly contrasted chemically. But in certain regions there appears to be a gradual shifting in chemical composition of the rocks from one locality to another. This is well illustrated in the region embracing the Yellowstone National Park, the Crazy Mountains, Castle Mountain, Little Belt Mountains, Highwood, and Bearpaw Mountains in Montana.[1] The series of rocks at each of the localities named becomes relatively richer in alkalis from the south northward, potash assuming a very prominent rôle. The analyses from these localities to the number of 175 are compared with one another in Diagram 5, which shows the gradual shifting of the alkali-silica ratios.

In general a more or less gradual shifting of chemical characters with increase in alkalis obtains for genetic series of rocks from the Great Basin in Nevada, Idaho, and Utah eastward across the Rocky Mountains to the Black Hills, S. D., Leucite Hills, Wyo., Cripple Creek, Colo., into Arkansas and southward into the Transpecos region of Texas. Throughout this vast region there are innumerable genetic series of igneous rocks. The series from somewhat remote parts of the region are chemically quite clearly distinguished, but series from intermediate localities grade into one another so that there are in reality series of series. The term series in the sense here used applies to all igneous rocks of one petrographical province that belong to one period of volcanic activity, which may be of very great

[1] IDDINGS, J. P., The Eruptive Rocks of Electric Park and Sepulchre Mountain, Yellowstone National Park, 12th Ann. Rep. U. S. Geol. Survey, 1892, pp. 569–664. Origin of Igneous Rock, loc. cit. Absarokite-Shoshonite-Banakite-Series, JOUR. GEOL., Vol. III, Chicago, 1895, p. 935.

WEED, W. H. and PIRSSON, L. V., Geology of the Castle Mountain Mining District, Montana, loc. cit. Highwood Mountains of Montana, Bull. Geol. Soc. Am., Vol. VI, Rochester, 1895, pp. 389–422. The Bearpaw Mountains of Montana, Am. Jour. Sci., Vol. I, 1896, pp. 283, 351; Vol. II, pp. 136–188. Also Bull. U. S. Geol. Survey No. 148, Washington, 1897, pp. 117–136, 142–157.

duration, embracing a whole geologic period, as, for example, the Tertiary. It may include a number of lesser series of eruptions localized within the province, as at centers of eruptions such as volcanoes; and may be highly complex, having many branchings. In some series the range of chemical variations is comparatively small, in others it is comparatively great. Examples of these appear in the rocks of the Yellowstone Park and in those of the Christiania region, whose analyses have been plotted in Diagram 6; the red spots representing those of the Christiania region.

If more limited genetic series are compared it is found that in one case the chemical variation is chiefly in the line of silica, from much to little, accompanied by abundance of feldspar molecules for the higher silica, and abundance of ferromagnesian molecules for lower silica. While in another case the chemical variation affects the silica but slightly, and shows itself in the relative abundance of alkalis and alumina on the one hand, and of ferromagnesian molecules on the other.[1] The definition of a genetic group or family of rocks, as expressed chemically, must, therefore, be very flexible and indefinite.

The natural consequence of the variability of composition among rocks of one genetic series, and of the existence of genetic series closely similar to one another chemically, is the close resemblance of some rocks of one series to certain rocks of other series. And since the differences in most cases consist in the relative proportions of the same chemical elements, it follows that some rocks of one genetic series are quite as much like certain rocks of another series as these are like other rocks of the same series. Hence, a chemical definition broad enough to cover several closely similar rocks of one genetic series may apply equally well to similar members of another genetic series, and it cannot be framed so as to exclude them. In other words, it follows from the very nature of a chemico-physical differentiation of rock magmas that some rocks belong-

[1] IDDINGS, J. P., Absarokite-Shoshonite-Banakite Series, JOUR. GEOL., Vol. III, Chicago, 1895, p. 935.

ing to different genetic series, or to different petrographical provinces, may be chemically alike.

The same is true with regard to the mineralogical characteristics of rocks. Since these are primarily dependent on the chemical composition of the magma of each rock, and also on the physical conditions attending its solidification, it follows that the minerals composing certain members of any genetic series of rocks must be like the minerals in some members of other genetic series. Definitions based on the character and proportions of these minerals must apply equally well to members of several genetic rock series.

Moreover, the texture, granularity, and physical aspect of rocks depend on both the composition of the magma and the physical conditions under which solidification took place. The latter are independent of geographical position; that is, are not localized, but are universal, and cannot be peculiar to any petrographical province. They depend on the environment of the magma in each instance, and magmas in different provinces may have existed amid similar environment and have been exposed to almost identical physical conditions.

The most distinctive features of igneous rocks, then, their chemical and mineral composition and texture, cannot serve as means of discrimination of rocks of all genetic series, consequently a group or class of rocks which may be of essentially the same natures as regards these essential qualities may embrace rocks belonging to different genetic series. It follows from this that the classing of all known igneous rocks into groups that shall have essentially the same chemical and mineral composition and texture, and which may be designated by definitions expressed in terms of these qualities, must disregard the genetic relations among the rocks of different classes.

The nature of a rock-body or geological unit.—In the foregoing discussion the term rock has been used as though applied to a mass having in each case some definite composition and texture. But it is well known that in large masses this is not always the case. In some masses the texture varies in different parts of the whole; in others the chemical and mineral composition varies.[1] These variations may be slight and within what may be considered the limits of variation for a given class of rocks, or they may be so great as to exceed these limits, and different parts of one continuous rock-mass may have characters belonging to different classes of rocks in the usual sense. The same variations and relations exist between different parts of some rock-masses as those just mentioned as existing between some rock members of various genetic series of rocks, and for exactly the same reason. Hence, definitions of rocks based on the essential, material characters—composition and texture—cannot be made so as to discriminate always between various rock-masses.

Rock-masses of this kind are geological bodies, in that they form integral parts of the crust of the earth, such as lava streams or sheets, dikes, laccoliths, stocks, etc. Rock-masses or rock-bodies, in distinction from rocks as considered in this discussion, can not be grouped in classes on the same basis as those on which the rocks can. They may be classified according to their form or dimensions, or their mode of occurrence, or according to some general idea of composition, as homogeneity and heterogeneity.

A knowledge of the characteristics of all rock-bodies as such is necessary to a proper understanding of the mode of occurrence of igneous rocks, and is essential to any comprehensive treatment of the science of petrology.

The nature of genetic series of rocks.—The character of series of rocks that occur associated in any region so as to be considered as genetically related, differ widely in different cases. Aside from the fact that all those in one region may have solidified within the crust of the earth, while those in another region may have reached the earth's surface and have consolidated at the surface and also within the crust, there are the subsequent geological events that have transpired in each case since solidification whereby the present exposure of the rocks has been

[1] IDDINGS, J. P., Genetic Relationships among Igneous Rocks, JOUR. GEOL., Vol. I, Chicago, 1893, pp. 833–844.

brought about. This may reveal parts of all the rock-bodies originally present, or much more probably only a certain number of all once in existence, some having been entirely removed or still remaining covered. The rocks exposed in any region seldom represent the whole series of varieties that actually exist or did exist in the region. Consequently some series or associations represent comparatively few varieties of rocks, and these often quite different from one another, as when only basalt, rhyolite, and one or two varieties of andesite occur in a region, whereas other series exhibit many varieties and frequent transitions from one to another as in the dissected volcanoes in the Yellowstone Park region. Again, it is found that the range of rock varieties in some regions is limited, and in others is very wide, indicating less differentiation of the parent magma in one case than in another.

A knowledge of these associations in various regions leads to a comprehension of the laws governing the production of varieties of igneous rocks, both their probable differentiation from a parent magma, and something of the mechanism of their eruption, consequently its importance in a treatise on petrology cannot be overestimated. The consideration of these relationships is absolutely essential to a right conception of the true nature of igneous rocks.

Classification of igneous rocks and the didactic treatment of petrology.—It is hoped that the foregoing discussion has made it apparent that a systematic classification of all kinds of igneous rocks cannot be put on the same basis as a philosophical treatment of the subject-matter of petrology, which takes cognizance not only of the material character of rocks, but also of the laws governing their production, eruption, mode of occurrence, and solidification, as well as their subsequent alteration.

The object of a classification of rocks is clearly the bringing together of those that have like characters in order that they may receive a common name, and that their descriptions may be systematically arranged for convenient reference. The use of names common to all similar rocks instead of individual names, such as are given to men, is also solely for convenience; it being considered more useful to emphasize the characters common to the rocks bearing a common name than those which might distinguish them as individuals. Moreover, it must be admitted that there is need of a systematic arrangement of descriptions of rocks, and that the descriptions of all similar rocks should be found together.

With the need of systematic classification of descriptions of rocks is an equal necessity for a systematic nomenclature. The present nomenclature is an inheritance of the most fortuitous creations of the earliest investigators, whose knowledge was of necessity often imperfect or faulty, and of recent petrographers, whose suggestions of names have been based on no uniform system. The earlier names have undergone such changes of definition as in more than one case to shift them entirely from their original application. Terms derived from geographical localities, from physical characters, or from mineral components, have been used indiscriminately. Rocks differing from one another but slightly have in some cases received totally different names, in other cases names alike except for qualifying prefixes. The time has nearly arrived for a complete reformation of petrographic nomenclature. The need is urgent but the condition of our knowledge at present is scarcely such as to warrant the immediate attempt to create a systematic nomenclature. When it is devised it should not only be sufficient for present needs, but should be capable of further development along with the growth of our knowledge of the rocks themselves.

The object of a treatise on igneous rocks should be to convey an idea of the origin and geological history of such rocks, their intricate relationships with one another, and their material characteristics. To accomplish this, the known facts may be presented in a number of ways, and the subject may be approached from different directions. Different methods of procedure may commend themselves to different writers, and may be followed with equal success. But there should be one systematic nomenclature based upon some universally accepted classification. The exact nature of this classification has yet to be determined.

JOSEPH P. IDDINGS.

EDITORIAL.

AMONG the various organizations working for the promotion of science, the state academies of science have recently become prominent, particularly in the middle west. The Ohio, Indiana, Wisconsin, Minnesota, Iowa, Nebraska, and Kansas academies are doing an important and highly valuable work. In most cases their meetings are held at some time during the winter holidays, and they bring together a large proportion of the influential men of science of their respective states. Our country is a large one and to many a scientific worker the pilgrimage eastward to the winter meeting of his special society is something only to be undertaken after careful consideration of ways and means. To such a one the state academy is a real boon, and in any event the coming together of men of scattered but related fields of work is perhaps as productive of good as the meeting of specialists alone.

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THE state academy is, however, making a peculiar place for itself aside from serving as a meeting place for various scientific workers. It is rapidly becoming a molder of public opinion on the numerous semi-public scientific questions which are constantly springing up. It is the adviser of the legislature in matters of scientific work and its potency in that direction has been instanced in the part taken by the Wisconsin and Iowa academies in securing the legislation necessary for geological and natural history surveys. In several of the states this semi-public position of the academy has been recognized, and the state has undertaken to publish the proceedings.

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IN the recent meetings of the state academies the geologists have as usual taken an active part. The Minnesota meeting, being the twenty-fifth anniversary, was celebrated by a very attractive programme. Papers were read by Winchell, Grant, Sardeson, Berkey, and others upon various geological problems. The Iowa programme included papers by Todd, Calvin, Keyes, Udden, Sardeson, Bain, Leverett, and others and was particularly interesting to students of the drift. The Wisconsin programme embraced papers by Van Hise, Collie, Hobbs, Lurton, Slichter, with a report of progress of the Geological and Natural History Survey by Birge and Marsh. The Indiana programme was also a strong one, and the Nebraska meeting, held some time earlier, was well attended. The publication of the proceedings of these meetings will be awaited with interest. H. F. B.

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Messrs. Spring and Rowland have recently communicated to the Belgium Academy a series of observations made upon the amount of carbonic acid contained in the atmosphere during the year. They give the result of 266 determinations made in the city of Liege, Belgium, on one side of which there is an industrial and on the other an agricultural district. The average amount of carbonic acid contained in ten thousand parts of air was 5.1258 parts by weight and 3.3526 parts by volume. These gentlemen remark that this is more than the amount contained in the air of Paris, which is 4.831 parts by weight and 3.168 by volume. The large amount at Liege is owing not only to the large iron works there but also to the fact that the city is surrounded by coal mines. To this the authors attribute the greater heat of the city as it is well known that a small amount of carbonic acid in the air causes the absorption and prevents the radiation of heat. They also attribute the cold weather of May to the diminution of the carbonic acid caused by its consumption by the exceptionally vigorous growth of leaves at that season. Their observations show that a fall of snow will increase the amount to 3.761 by volume and that in cloudy weather the amount was 3.571 parts and that there was always a larger amount in winter than in summer. They also found that the amount was diminished by high winds but increased with a high barometer. (Egleston Thomas, *Trans. Am. Soc. Civil Engineers*, Vol. XV, p. 650, New York, 1886.) H. F. B.

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The attendance at the Montreal meeting of the Geological Society of America was small, but the session was both pleasant and profitable. The hospitality of the people of Montreal, always cordial, was notable for its warm-heartedness. The interest and importance of the papers compared very favorably with those of the preceding sessions, and in several notable instances possessed peculiar interest. The presidential address of Dr. Orton was an admirable exposition of the theoretical aspects of petroleum and was made attractive not less by the charm of its manner than by the judiciousness of its matter. The pleistocene papers as usual led in number, but the preponderance was but slight. The petrological papers followed them closely in number and perhaps surpassed them in fullness and in the labor of preparation. Two of them were especially notable for their careful elaboration. It was gratifying to observe a relative increase in palæontological papers. It has been a source of deep regret to many American geologists that palæontologists have in recent years so largely drifted in the direction of phylogeny (important as that is) and that the study of faunas and floras as such and as factors in the history of the earth has not found larger expression in the papers of the Geological Society. The evolution and migration of faunas and floras is comparable if not superior in importance and interest to the evolution of species and families, and merits an ample share of palæontological effort. Papers upon regional geology, which have always constituted a notable proportion of the programme, held a fair place at the Montreal meeting. The dynamical papers were few, but the peculiar interest which attached to the experiments of Dr. Adams on the flow of rocks under pressure made full atonement for the scantiness of their numbers. The important paper of Professor Van Hise on "Shortening of the Outer Part of the Earth" was read by title only. Physiographical papers which have sometimes occupied a prominent place on the programme found notable expression in but a single presentation.

The following is a list of the titles of the papers offered. Abstracts of a portion of these appear in this number of the JOURNAL and others will follow:

"Notes on the Sands and Clays of the Ottawa Basin." By R. W. ELLS.

"Topography and Glacial Deposits of the Mohawk Valley." By ALBERT P. BRIGHAM.

"Topography and History of Jamesville Lake, N. Y." By EDMUND C. QUEREAU.

"Location and Form of a Drumlin at Barre Falls, Mass." (By title.) WILLIAM H. NILES.

"Drift Phenomena of the Puget Sound Basin." (By title.) By BAILEY WILLIS.

"Niagara Gorge and St. David's Channel." By WARREN UPHAM.

"Notes on the Moraines of the Georgian Bay Lobe of the Ice-Sheet." By FRANK B. TAYLOR.

"Notes on the Geology of Montreal and Vicinity." By F. D. ADAMS.

"Notes on the Geology of the Rocky Mountains of Montana." By WALTER H. WEED.

"Marine Cretaceous Formations in Deep Wells in Southeastern Virginia." By N. H. DARTON.

"The Cretaceous Series of the West Coast of Greenland." By CHARLES SCHUCHERT and DAVID WHITE.

"Note on Lepidophloios Cliftonensis." By SIR WILLIAM DAWSON.

"Omphalophloios, a new Lepidodendroid type." By DAVID WHITE.

"The Mastodon in Western Ontario." By H. M. AMI.

"Mastodon and Mammoth Remains Found near Hudson Bay." By ROBERT BELL.

"Fossil-like Forms in Sault Ste. Marie Sandstone." By ROBERT BELL.

"Weathering of Alnoite in Manheim, N. Y." By C. H. SMYTH, JR.

"Syenite-Porphyry Dikes in the Adirondack Region. By HENRY P. CUSHING.

"Nodular Granite from Pine Lake, Ontario." By FRANK D. ADAMS.

"Chemical Composition of the Granite from Pine Lake, Ontario." By NEVIL N. EVANS.

"Clastic Huronian Rocks of Western Ontario, and the Relation of Huronian to Laurentian." By A. P. COLEMAN.

"The Classification of Igneous Rocks." By JOSEPH P. IDDINGS.

"The Geological *versus* the Petrographical Classification of Igneous Rocks." By WHITMAN CROSS.

"Geological Probabilities as to Petroleum." (President's address.) By EDWARD ORTON.

"On the Occurrence of Corundum in North Hastings, Ont." By A. E. BARLOW.

"The Harvard Geographical Models." W. M. DAVIS.

"Experiments on the Flow of Rocks, now being conducted at McGill University." By FRANK D. ADAMS and JOHN T. NICOLSON.

"Estimates and Causes of the Shortening of the Outer Part of the Earth." By C. R. VAN HISE. (By title.)

"New Geothermal Data from South Dakota." By N. H. DARTON.

"Concentric Weathering in Sedimentary Rocks." By T. C. HOPKINS.

"Note on an Area of Compressed Structure in Western Indiana." By GEORGE H. ASHLEY.

T. C. C.

Authors' Abstracts.

PAPERS READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.

Sands and Clays of the Ottawa Basin. By R. W. Ells.

The paper describes the leading physical features of the Ottawa River basin, which comprises about 130,000 square miles, and which includes numerous large streams, both from the north and south. The elevations of the height of land on the north, which divides the Ottawa waters from those which flow into James Bay, are given as ranging from 900 feet at Grand Lake, one of the large expansions in the upper part of the Ottawa River, to about 1100 feet near the source of the stream. Further east at the head of the St. Maurice, the elevation is somewhat greater, probably between 1300 and 1400 feet. The height of the divide to the north of Lake Temiscaming is given as 923 feet, while the elevation of Lake Temagami, which empties from the south into Lake Huron and from the northeast into the Ottawa, is 967 feet above sea. The height of land along the southern rim of the basin ranges from 645 feet at Lake Nipissing to about 1400 feet at the head waters of the Petewawa and Madawaska rivers, decreasing to 417 feet at the head of the Rideau.

Over all this area to the height of land, apparently continuous deposits of a blue clay, similar in character to the recognized marine clays of the lower Ottawa and St. Lawrence basins, can be seen. These have in places a thickness of over 100 feet, and they are overlaid over a great portion of the basin by sands, similar in character to the well-known Saxicava sands which contain marine fossils further east. In the eastern part of this area well defined deposits of these clays and sands holding marine shells, are found at elevations of nearly or quite 600 feet above sea level, while shore lines and old beaches, also of marine origin, are to be seen along the north side of the St. Lawrence, as well as along the lower Ottawa, which range in elevation from 600 to at least 1000 feet above present sea level. The bones of a whale have been obtained from a large kame-like ridge near Smith's Falls at a height above sea of 440 feet, the skeleton being reached in the excavation at a point 50 feet from the outer zone of the ridge. This elevation is nearly 200 feet above the present level of Lake Ontario. The indications of submergence, as seen along the sides of the Montreal mountain, are clear at elevations from 220 to 750 feet or nearly to the summit. Similar high level beaches are found along the slopes of the mountain ranges in eastern Quebec to a height of nearly, or in places quite 1000 feet, so that it may be considered as fairly well established by the latest evidence that this portion of Canada was submerged, subsequent to the glacial period, to a depth of at least 1000 to 1200 feet. All the high level beaches in the St. Lawrence and Ottawa valleys front directly to the open estuary of the St. Lawrence River, and there were, in so far as can now be seen, no barriers to interrupt the inland spread of the sea between that river and the upper great lakes. The submergence mentioned would carry these waters over the height of land in nearly every part of the Ottawa basin and support the view now put forward that the clays which are found on most of the portages at the highest levels are marine. It is probable also on this theory that the Erie clays, which are very similar in character to those of the lower Ottawa, and unconformable to the overlying series, are the true equivalents of the Leda clays of the eastern area, though this point requires further detailed examination before the exact relations of the fresh water deposits of this part of Canada to the underlying clays can be completely established.

Note on an Area of Compressed Structure in Western Indiana. By GEO. H. ASHLEY.

As is well-known, the rocks of Illinois, most of Indiana, and part of Kentucky form a basin with gently dipping slopes, and where local evidences of stress are observed they usually indicate tension. Thus the faults are commonly tension or normal faults, and the joints are perpendicular and open. Recently several local areas of disturbance have been observed and this note is intended to call attention to one of these. In this case the evidence of considerable tangential pressure is seen in (1) overthrust or pressure faults, (2) coal beds compressed laterally until they become several times their original thickness; (3) in place of perpendicular open joints, confined to the coal and with faces even but not polished or showing any indication of rubbing, such as are common in the region as a whole, are found regular oblique joints, cutting the roof and floor as well as the coal, and having their faces much slickened. These joints are evidently shearing planes, and show signs of incipient movement, or in some cases, as in one of the figures given, they become fault planes allowing the lower of two coal beds twenty feet apart to slide an unknown distance up over the upper bed. The main system of joints dip to the north, a second set sometimes developed dip to the south. The pressure acted with the general strike of the rocks. The area described covers a few square miles southwest of Asherville, Clay county, Ind. The structure has been disclosed by the operations of mining.

Syenite-porphyry Dikes in the Adirondacks. By H. P. Cushing.

Interesting dikes of pre-Potsdam age have been recently found in the Adirondacks which constitute the complementary rocks to the diabases of the region. Basal conglomerates of the Potsdam contain pebbles derived from them. On the other hand, together with the diabases, they comprise the only unmetamorphosed pre-Potsdam rocks known in the district.

These dike rocks are made up of feldspar, quartz, and biotite, with or without hornblende, and with accessory iron ores, apatite, augite, titanite. Both orthoclase and albite feldspar are present, commonly intergrown as microperthite. The rock is porphyritic, both feldspar and biotite occurring in two generations, the latter only sparingly. The feldspar largely predominates over all other minerals, constituting from 60 to 80 per cent. of the rock. The ground mass structure is trachytic or orthophyric.

Chemically the rocks are characterized by high alkali and low lime-magnesia percentage, and rather low ratio of alumina to silica. They belong to the alkali-syenite group of Rosenbusch. Their bunched distribution and mineralogic similarity indicate that they were products of a common magma, and if that be so they afford an interesting case of magmatic differentiation as they range from 69 to 52 per cent. of silica. With decreasing silica the lime, magnesia and alkali percentages rise, the latter retain their preponderance.

The greater number of the dike rocks would be classed as syenite-porphyries, nordmarkite, and pulaskite types. The more acidic representatives belong properly with the alkali-granites. The most basic rocks represent an undescribed type, so far as the writer is aware, being very basic mica-syenite-porphyries.

Together with the diabases these rocks form an eruptive assemblage quite similar to that which characterizes Keweenawan time in the upper lake region, nor, since there is in each case the same relationship to a younger unconformable sandstone of upper Cambrian age, and to an older mass of gabbroic intrusives, can they depart widely from them in age.

Leaving out of the question the older gneisses of somewhat doubtful origin, there were three distinct periods of igneous activity in the Adirondack region. The earliest gave rise to gabbros and granites, the next to diabases and syenite-porphyries, the last to bostonites and various basic rocks (camptonites, monchiquites, etc.). Analyses show an astonishing agreement between the acidic rocks of each period on the one hand and the basic rocks on the other. Though a long time interval elapsed between each, magmatic relationship seems not unlikely.

Accumulating evidence seems to the writer to indicate the possibility that three similar periods were characteristic of the entire shore line of the Canadian and Appalachian protaxes, and that such possibility should be added to the working hypotheses of all workers in that field.

(Other Abstracts, Reviews, and Publications deferred to next number.)

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BRAZILIAN EVIDENCE ON THE GENESIS OF THE DIAMOND.

The extensive working of the "dry diggings" of South Africa has thrown a light on the original associates and probable mode of origin of the diamond, which it would be vain to look for in the ordinary type of diamond fields as known in other parts of the world, since all of these, with rare and imperfectly known exceptions, correspond almost exactly with the river washings of the Cape district. The group of mines about Kimberley have shown beyond a doubt that here at least the association of the diamond is with an eruptive rock of ultra basic composition, and, although opinions differ as to the exact mode of origin, all authorities seem to agree on the main fact that in some way this association is a genetic one. To one familiar with the Brazilian diamond fields this conclusion seems a startling one and utterly inapplicable to them. The evidence in its favor, if any exists, is either concealed and has been overlooked, or, as at first sight seems most probable, a totally different association is presented, necessitating the hypothesis of the formation of the mineral under a far wider range of conditions than has been admitted by the students of the Kimberley occurrence. In the present paper it is proposed to discuss the observations, in great part unpublished, that have thus far been made in Brazil bearing upon the question of the genesis of the diamond, with a view of seeing in how far they are in accord, or disaccord, with the much more complete observations in the South African mines.

With two exceptions, which will be more fully discussed below, all the known Brazilian diamond washings are in material — sand and gravel — which has clearly been transported from its place of origin and equally clearly contains the débris of a greater or less variety of rock types, some one or more of which may reasonably be presumed to have a genetic relation to the diamond. As the latter, however, is almost invariably found free in such deposits, or attached to the other elements by a cement, usually limonite, which is visibly of secondary origin, such deposits throw little light on the history of the gem. For the most part these deposits are of quite recent origin, having evidently been formed by the action of the present drainage agencies. In a few cases the gravel has been attributed[1] to the disintegration of conglomerates of various ages, which in one case is presumed to be very great. The age of the gem is thus carried back to a more or less remote geological period, but no other essential addition is made to its history. The concentrates of the rarer and heavier elements of these gravels obtained by the miners in their operations contain many rare and interesting minerals which have attracted the attention of mineralogists, but, thus far, the hopes that have been entertained of tracing the diamond to its original home by means of these satellites, have proved illusive, since none of them have proven to be sufficiently constant to give more than merely presumptive evidence. The few cases that have been reported of diamonds included in other minerals, as iron ores and rarely quartz and anatase, refer to minerals that are known to be readily formed by secondary action, and thus are not necessarily contemporaneous with their inclusions.[2]

The associates of the diamond in these gravels are naturally fragments of all the rocks capable of resisting decay and the

[1] DERBY: Am. Jour. of Sci., 1882, XXIV, p. 34.

[2] The specimen described by Eschwege, who attributed great importance to it (Geognostisches Gemälde, p. 430; Beiträge zur Gebirgskunde Brasiliens, pp. 213 and 341), and which is now in the Heuland collection in the British Museum, is apparently a cleverly executed fraud. The limonite and scorodite of the drusy cavity in which the diamond rests present the peculiar and very characteristic aspect of these minerals

wear of transportation that have contributed to the deposit, together with the isolated minerals derived from the breaking down of these rocks and of such others as have entirely disappeared as rock-masses and are now only represented by the more resistant of their constituents, which have been more or less completely assorted according to their resistance to disintegration and to wear, to their specific gravity and to the size of grain. These isolated minerals, the *formation* of the miners, who attach great importance to them, can in some cases, as of zircon, monazite, xenotime, etc., be referred with tolerable certainty to original eruptive rocks, though they may, and in many cases doubtless have, passed through others before reaching their present place in the gravels; others, as staurolite, disthene, etc., can with equal certainty be referred to metamorphosed clastics, but by far the greater part, as quartz, the iron and titanium oxides, tourmaline, garnet, and many others might be from either eruptives or metamorphosed clastics, or from both. The minerals which can with more or less probability be attributed to eruptive rocks, are not so predominant or so constant in their occurrence that any particular significance can be attached to them. Their evidence, so far as it goes, points rather to the acid eruptives, as granites, etc., than to the ultra basic types of the Kimberley district.

In only one Brazilian mine, so far as known, are basic eruptives a characteristic feature, and in this the conditions are such that the association seems to be accidental rather than genetic. This is the Agua Suja (dirty water) mine in the Bagagem district of western Minas Geraes, which has been excellently studied by Messrs. Gonzaga de Campos, Hussak, and Calogeras,[1] though

from the gold mine of Antonio Pereira, near Ouro Preto, which is the only known Brazilian locality of scorodite, but is not known as a diamond locality. The specimen is reported to come from the Abaieté district to the west of the São Francisco, but no other specimens of scorodite, or of limonite of this character, are known from that region, where, moreover, only gravel deposits had been worked, whereas the specimen in question is evidently from a mine, and not from a deposit of transported material.

[1] Gonzaga de Campos: Jazidas Diamantiferas de Agua Suja, Rio de Janeiro,

much is yet to be learned regarding this unique deposit. The region is characterized by inclined strata of micaceous schists, in part staurolitic, which are regarded as metamorphosed clastics, with intercalations of amphibolites, which are almost certainly metamorphosed eruptives. This schist series is cut by dikes of granite which, so far as observed, are characterized by muscovite either alone or in association with biotite, and which are generally tourmaliniferous. Quartz veins which frequently carry a little mica are also common. Upon this group of schists and granite rest horizontal beds of soft sandstones, with intercalated layers, or sills, of trap—augite-porphyrite or melaphyre—which are presumably of Triassic age. In the same region, although not definitely known in the immediate vicinity of the mine, there is another obscure eruptive group which has furnished material characterized by grains of pyroxine, perofskite, and magnetite, to beds of clay and impure limestone that overlie the sandstone and trap, and, in places, present something of the aspect of ash-beds or volcanic breccias. This group, though very imperfectly known, is certainly distinct from the traps, and its probable relations will be discussed below.

The diamond-bearing bed of Agua Suja is a thoroughly decomposed conglomerate, or breccia, in which both matrix and the included pebbles are transformed into clay. The original angular outline of the pebbles (or rather bowlders, as they are often of considerable size), can, however, be recognized, as also, in many cases, the type of rock to which they belonged. The various types of the schists and granites upon which the diamantiferous bed rests in part (in part also on sandstone and trap) are recognizable, as well as masses of the sedimentary and later eruptive series. Fragments of opal, which may be of secondary origin, constitute a peculiar feature when this mine is compared with others of the same region (Bagagem) or of the other diamantiferous regions of Brazil. Still more peculiar and

1891. E. HUSSAK: In the above cited pamphlet and in Relatorio da Commissão Exploradora do Planalto, Rio de Janeiro, 1894. J. P. CALOGERAS: Revue Universalle des Mines, XXIX, 1895.

characteristic is the presence in great abundance of magnetite and of a magnetite rock, which Dr. Hussak has succeeded in tracing to a special magnetite-perofskite type found by him near Catalão, in the state of Govaz.[1]

This last element of the diamantiferous bed cannot be referred to any of the known rocks of the region, but it points in the same direction as the above mentioned eruptive elements of the limestone and clay beds that are known to occur in the region and that may be presumed to extend to the immediate vicinity of Agua Suja. These elements, pyroxene, perofskite and magnetite, suggest a type of basic eruptive passing into an iron ore such as has actually been met with in the Jacupiranga district of the state of São Paulo in genetic relations with various nepheline-bearing rocks, the whole constituting a typical volcanic series.[2] As a somewhat similar volcanic center is known at Caldas[3] at no great distance from the Agua Suja region, there is a reasonable probability that another one may exist in the immediate vicinity, and that it may have furnished the problematic material of the diamantiferous bed. This last is not clearly referable to the present drainage conditions of the country and is very likely to prove to be an ancient conglomerate, or breccia, possibly in relation with the eruptive manifestation that is presumed to have contributed to its elements.

The Agua Suja occurrence thus offers a certain number of analogies with those of the Kimberley district which are entirely lacking in the other Brazilian localities, so far as they are known. It is especially to be noted that the absence of these analogies is as conspicuous at the nearest locality, Bagagem, only about twenty miles distant in the same river basin, as at any other. The country rock both at Kimberley and Agua Suja is horizontal, of approximately the same age (late palæozoic or early secondary) and with intercalated sills of trap of very similar character and composition, but which in both cases has no

[1] Neues Jahrbuch, 1894, II, p. 297.

[2] Derby: Am. Jour. of Sci., XLI, 1891, p. 311.

[3] Derby: Quart. Jour. of the Geol. Soc., 1887, p. 457.

apparent relation with the occurrence of the diamond; the deposit is conglomeratic, or brecciated, and in both cases the most characteristic elements of the conglomerate represent rocks of an ultra basic type, and in both the diamond is presumed to be an element of the cement rather than of the included pebbles; perofskite and garnet (pyrope) are characteristic accessories (garnets though frequent in most Brazilian sands and gravels are exceptionally rare in those of the diamond washings; those of Agua Suja present the rare cubic habit); the diamonds *seem* to be distributed with a considerable degree of uniformity throughout the mass.

With these analogies are, however, associated differences that are, in appearance at least, of equal if not greater importance. The Agua Suja deposit is a bed, not a volcanic neck; in it clastic elements, of a much more varied character than those of Kimberley greatly predominate over those of eruptive origin, which also are more varied in character; the cement is apparently clastic rather than eruptive; the eruptive elements, exclusive of the trap, probably represent basic phases of the nepheline- or augite-syenite type of rocks and not the peridotitic, and there is as yet no direct evidence that they have anything to do with the diamond; the original matrix of the garnets is unknown and there is no evidence that their association with the diamond and with the basic eruptives is direct and not accidental. If, as is quite within the range of possibilities, eruptive necks of the Kimberley type should be discovered in the Agua Suja region, or contemporaneous (?) sedimentary deposits of the Agua Suja type in the Kimberley district, some of these differences would doubtless become analogies, but that of the *probable* original rock type would still remain and would require an extension of the views at present held regarding the type of eruptive rocks with which the diamond is associated. If, as some hold in regard to the Kimberley occurrence, the diamond is the product of metamorphic action on carbon-bearing rocks and not an element of the eruptive rock itself, this last difference would lose much of its importance. In this case, the Kimberley and Agua Suja occurrences would fall into line as phases of the same phenomenon of contact metamorphism, and to this it may be added that the, at present, striking differences between the latter and the other known Brazilian occurrences would be reconcilable.

Before leaving the topic of African analogies it may be mentioned that in another Brazilian diamond region, that of the river Abaiete, a porphyritic peridotite (picrite-porphyry) with perofskite, quite similar to that of Kimberley as described by Lewis and others, has been found. Its known occurrence is, however, at some distance from the diamond washings and no relation between the two would ever have been thought of if it had not been for the Kimberley occurrence.

In the oldest and best known of the Brazilian diamond fields, that of Diamantina in Minas Geraes, there is an apparent relation, first noted by Eschwege in 1822 and confirmed by all subsequent writers, between the distribution of the diamond and that of the quartzose rock known as itacolumite. Eschwege who first described this rock[1] recognized a schistose and a massive type, the latter often presenting a conglomeratic appearance and, occasionally, an apparent lack of conformability with the former.[2] As, however, both types, and the schists associated with the schistose one, were considered as constituting a single division of the primitive group and as having a special, and non-clastic, mode of origin, the two were not separated and the question of the conglomeratic character was left by Eschwege as an unsolved problem. The predominance of the massive type of itacolumite in the Diamantina region was noted and from this a genetic relation between the rock and the diamond was inferred, an hypothesis which has become deeply rooted in mineralogical literature. About 1840, and after the publication of Eschwege's various works, diamonds were actually discovered and worked in this rock at Grão Mogol, some 100 miles, more or less, to the northward of Diamantina. The locality was

[1] Geognostisches Gemälde von Brasilien, und wahrscheinliches Muttergestein der Diamanten, Weimar, 1822.

[2] Beiträge zur Gebirgskunde Brasiliens, Berlin, 1832, pp. 210, 216.

visited and minutely described by Helmreichen[1] who confirmed Eschwege's views of the genetic relation of the diamond with itacolumite, although he confessed a doubt as to whether the rock, which had a conglomeratic aspect, might not be of clastic origin. Subtantially the same view was taken by Heusser and Claraz[2] who also visited the locality and who considered itacolumite as a quartzose phase of hornblende-schist and attributed the apparent pebbles of the diamond-bearing bed to concretionary action. In 1882, the present writer showed[3] that in the Diamantina region the massive itacolumite of Eschwege really constitutes an independent formation resting unconformably on the upturned edges of a lower series to which the schistose type belongs, and containing elements derived from it, the diamond being probably one of these derived elements. Several of the "dry diggings" of the vicinity of Diamantina were cited as being probably disintegrated masses of this ancient and metamorphosed conglomerate and the Grão Mogol deposit, which was not seen, was referred to as being presumably another example of the same kind. Professor Gorceix who afterward visited the Grão Mogol locality, and who for the Diamantina and other regions accepted my view of the dual character of itacolumite as originally described, agreed with Helmreichen and Heusser and Claraz in uniting the diamond-bearing bed with the lower schistose itacolumite, but, in opposition to their view, he considered the whole series as clastic.[4] The pebbles, or pebble-like bodies of the old writers, of the diamond-bearing bed were thought to be derived elements, while the mica, pyrite and martite of the same rock were considered as authigenic. The question as to which of these two groups of elements the diamond should be referred was, on theoretic grounds, decided in favor of the latter, a view that was rendered necessary by that

[1] Ueber das Geognostische Vorkommen der Diamanten und ihre Gewinnungsmethoden auf der Serra do Grão-Mogor. Vienna, 1846.

[2] Zeitschrift d. deutsch. geol. Gesellschaft, XI, 1859, p. 448; Petermann's Mitth., 1859, p. 447.

[3] Am. Jour. of Sci., 1882, XXIII, p. 97; XXIV, p. 34.

[4] Bulletin de la Societé Géologique de France, XII, 1884, p. 538.

of the unity of the formation, since elsewhere the diamond was considered to be authigenic under different conditions in a different rock referred to the same geological series.

The question of the unity of the section at Grão Mogol and of the clastic origin of at least the upper portion to which, according to all authorities, the diamond is confined, is an important one in this connection, since, if Gorceix's view is correct, it involves that of two widely different modes of genesis for the diamond in the same field. Not having seen the place, it is with considerable diffidence that I venture to contest the views of the eminent authorities who have.

The accompanying figure, reproduced from one of Helmreichen's sketches, gives what seems to me to be a more accurate

FIG. 1.—Left bank of Corrego dos Bois, near Grão Mogol showing diamond-bearing bed (*a*, *b*). After Helmreichen.

representation of the actual aspect of the exposure than the somewhat diagrammatic section given by Gorceix, and it has the further element of authenticity of representing, at the base of the diamond-bearing bed (*a*, *b*), an apparent unconformability that is not in accord with the theoretic views of the author of the sketch. Numerous cases of a break in the succession have, on close examination, been observed in the Diamantina district that are much less apparent in the topographical features than the one presumed to be here represented. The two rocks are often found united in the same rock-mass in such an intimate manner that, given the almost perfect identity in aspect and character, one is frequently inclined to doubt the evidence of his senses even after unequivocal proofs of the existence of a break have been detected. Similar cases of a complete blending of his massive and schistose types are graphically represented in other sketches given by Helmreichen which can best be interpreted on the hypothesis of an unconformability. In the present case, it seems to me that, admitting the accuracy of this sketch, the appearance of a break is so evident that before rejecting it most geologists would require much stronger evidence than has yet been presented.

A recent examination of a specimen with an inclosed diamond in the collection of the National Museum at Rio de Janeiro shows that the Grão Mogol rock contains both authigenic and allothigenic elements to either of which groups, leaving out of account considerations derived from other points, the diamond might with equal plausibility be referred. The predominant element quartz, which is presumably allothigenic, has by recrystallization, secondary enlargement, or other process, taken on the aspect of an authigenic element. The mica-like mineral (apparently a clintonite) and the iron minerals, pyrite and martite (magnetite ?) are certainly authigenic. Allothigenic elements are represented (leaving out of account the pebbles which are not well defined in the specimen in question) by distinctly rolled zircons. Specimens of typical *schistose* itacolumite, which though not from Grão Mogol may be taken as representing the supposed lower series of that place, present the same mixture of authigenic and allothigenic elements (the latter represented by well rolled zircons) and therefore the same evidence of clastic origin.

As the case stands at present, the evidence from Grão Mogol regarding the genesis of the diamond is inconclusive. The rock, whether one or two series are represented, is a metamorphosed clastic and no decisive evidence can be presented to place the diamond in the class of either the authigenic or allothigenic elements of this rock. If it belongs to the former class, two modes of genesis must be admitted in the same field in order to reconcile the occurrence with that at São João da Chapada ; if to the latter, the two occurrences can be explained on the hypothesis of a single mode of genesis, but, in case the series proves to be a single one, two periods of formation must be admitted.

For the question of genesis the most significant of the Brazilian localities is that of São João da Chapada near Diamantina

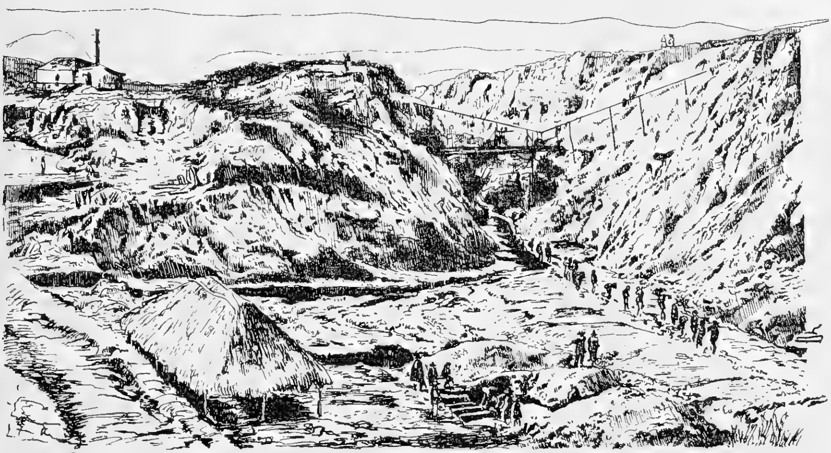


FIG. 2.— Diamond mine at São João de Chapada. The view is looking northward into the Barro mine, which runs into the Duro under the footbridge. The diamond-bearing layers dip into the bank at the right at an angle of about 50°. The open space in the foreground where the wash-house, concentration tanks (*canoas*), and heaps of diamond-bearing earth are located, represent the excavated portion of the left bank containing the upward prolongation of the diamantiferous layers. The wide trench near the pump-house at the left is apparently on the outcrop of one of the layers.

which has never been satisfactorily studied and described. The accompanying view, drawn from a photograph, which is also reproduced in Boutan's monograph on the Diamond in Fremy's *Enclyclopedie Chimique*, shows its character as a great gash resembling a railroad cutting across the crest of a high ridge that forms part of the divide between the waters of the Jequitinhonha and the São Francisco. Two mines, the Barro (clay) and the Duro (hard), opened on opposite sides of the ridge have come together in the center (the footbridge in the middle ground of the view marks the division) so as to form a continuous cutting nearly 500^m long with about 40^m of maximum depth. The Barro mine drains to the São Francisco through the Rio Pardo, an affluent of the Rio das Velhas, the Duro to the Jequitinhonha through the Caethé-merim. Both the Pardo and the Caethé-merim, but particularly the latter, are famous diamond streams.

The material exposed in the mines is a soft, soapy clay that is graphically described by Burton[1] as follows. "The material is a hardened paste of clay, whose regular and level stratification argues it to have been deposited in shallow water. The eastern side of the gap is the more ferruginous formation (terra vermelha); on the west it is mixed with beds of white sand. Below one foot of brown soil the argillaceous matter has the usual staining and marbling, glaring white like fuller's earth, with feldspar and kaolin, chocolate-brown or rape-colored with organic matter, blue-green with traces of copper [?], pink and rose purple, and dark yellow with various oxides of iron, especially hematite, and dark steel color with oxide of manganese [?]."

In the whole extension of this immense cutting, nothing approaching the gravel, the usual characteristic of a diamond mine, is to be seen and, with the exception of quartz veins, it is difficult to find a specimen that will resist the pressure of the fingers. The structure as exposed on the sides of the cutting, is much obscured by slides and weather action, and Burton's mistake of horizontal stratification and other indications of a shallow water deposit (thus corresponding, except in the character of the material with the other diamond deposits of the region and with the preconceived ideas of his informants, the miners) was a natural one on the part of a non-geological observer. The true nature of the clay as a decomposition product of schistose rocks had already been clearly recognized by Heusser and Claraz, who first described the mine and who iden-

[1] The Highlands of the Brazil, London, 1869, II, p. 129.

tified the original rock type as hornblende-schist,[1] giving the impression that the diamond occurred throughout the whole mass. The limitation of the diamond to certain streaks, or layers, was recognized by Burton, who gives the following excellent description of them.

"The richest lode (*corpo*) is No. 3, or the highest. The strike of the ribboned clays is north and south, bending [dipping] eastward. The lode inclines towards the higher grounds, and thus the owner hopes to find the gem-bearing strata spreading over the crest or watershed ridge which forms his property. Through the ferruginous sandstone (*borra*) and the white feldspathic matter run dikes and lines of fragmentary rock crystal, sometimes fibrous like arragonite, and often finely comminuted. Large pieces of imperfect specular iron and thin strata of quartz, yellow and brown at the junction, thread the argile, and I was shown a specimen of fine sandy conglomerate, blackened and scorified by the injection of melted matter.[2] The characteristics of this upper lode are a dryer clay, silica, a trace of copper [a green silicate of the nature of chlorite or serpentine?], of iron cement, and of Canga in small pieces; when the specular iron is in large pieces and abundant the rock is rich in gems. Its 'agulhas' [rutile] are iron-like bundles of needles welded together by intense heat; some are double, the fibers coming at obtuse angles. The 'Agulhas Cor de Ouro' have a burnished coppery surface, whence the name. Throughout all these corpos the diamonds are small, averaging perhaps a little under one grain or 64–72 per oitava; they are mostly crusted superficially

[1] Although Rose failed to find hornblende in the material submitted to him by Heusser and Claraz, it is possible that this idea was not entirely without foundation. Throughout the whole region traversed by them, intercalations and dikes of amphibolic and pyroxenic rocks are frequent in the schist series and generally they are the only ones of the not distinctly quartzose rocks whose original composition can be readily determined. As they usually give green decomposition products the staining referred by Burton to copper may, with considerable plausibility, be attributed to them. To judge from other exposures, the absence rather than the presence of such rocks at São João da Chapada would be a motive for remark.

[2] Probably a "Canga" or mass of sand or clay cemented by limonite common in such deposits.

with a light green tinge. Lower down we came to the middle or second body. Here the 'tauá' (feldspathic clay) was stiff and sandy, marbled with a fat, blue, muddy marl, which leaves upon the fingers a greasy, steely streak. It also yields a dark olive-green argile harder than the rest; like all the others it has consistence in situ, but when removed it crumbles to pieces after drying. Lieutenant-Colonel Brant gave me from this corpo a fragment of hard, large-grained clay, reddish colored with oxide, and showing a small brilliant imbedded in it. We then descended to the lowest formation. Here the clay contains very little sand, and much stained; the colors are white and blue, red and yellow, rosy, spotty, and in places dyed as with blood. Here also are found the 'Agulhas' in streaky bundles of iron-like asbestos. The sole of the pit is uneven with working, and in places 'horses,' 'old men,' and long walls of stiff clay have been left standing amongst the holes and gashes. From this point the several lodes are distinctly traceable in the walls of the basin." A more technical description is given by Gorceix[1] as follows: "One of the beds of bluish black color is composed of clay impregnated with oligiste in small fragments with rutile and anatase; the second of lithomarge with entire crystals of quartz having the same aspect as those of the topaz mines [near Ouro Preto]; the third and most important, with a thickness of more than 1.50^{m}, is composed of a series of beds of mottled clay. The stratification planes, parallel to those of the quartzites, are still clearly visible; the layers are undulated, folded like those of the intact schists that are found a few meters distant. Fragments of schist still almost intact occur in the midst of the clay. These beds of clay are traversed by small veins of quartz, granular or in bipyramidal crystals, oligiste and rutile, showing no signs of wear. Octahedral oligiste is found in certain points in extreme abundance impregnating the rock; in other points it is substituted by ordinary oligiste. The aspect of the gravel resulting from the washing of this clay is entirely different from that of the alluvial deposits, though composed of the same elements. The

[1] Comptes Rendus, 1881.

diamonds themselves of this region are easily distinguished from those of the rolled deposits by their rugose faces, sharp angles, and superficial greenish blue coloration."

On the occasion of my visit in 1881 only fallen masses that appear to represent the bodies 3 and 2 of the above description were to be seen, the operations of the mine being at that time suspended. One of these masses was so evidently a section of a vein that the conclusion was announced[1] that at São João da Chapada the diamond is a vein mineral accompanying quartz and an argillaceous rock of indeterminable character in the series of metamorphic schists. This conclusion was subsequently fully confirmed by Gorceix as the result of prolonged prospecting operations,[2] and thus one mode of occurrence of the diamond in the matrix was clearly established which, in appearance at least, is widely different from that at Gão Mogol and at Kimberley.

In the various papers by Gorceix and myself the schistose series of the gold and diamond region of Minas Geraes, in which the diamond occurs at São João da Chapada, is assumed to consist essentially of metamorphosed clastics, though no direct proof of this assumption is given. As regards the diamond-bearing layers, they are called veins, but no definite opinion regarding their mode of origin is expressed. For the question of the genesis of the diamond both these points are important.

All writers on the geology of this region are agreed that the characteristic formation is a great series of phyllites, quartz schists (itacolumite), iron-mica schists (itabirite), and limestone, and that this series constitutes a geological unit. This last point is assumed rather than proven, since there may be a break in the succession which has thus far escaped observation, just as that above indicated between the upper and the lower itacolumite was overlooked, or disregarded, by the older writers. For the purposes of the present discussion, however, it is of little conse-

[1] Am. Jour. Sci., 1882, Vol. XXIII, p. 97.

[2] Comptes Rendus, No. 25, 1881. Am. Jour. Sci., 1882, Vol. XXIII, p. 97, and Vol. XXIV, p. 34.

quence whether the series as here limited by the exclusion of the massive itacolumite of Eschwege is a simple or a composite one, since the evidence as to origin applies very directly to the beds in question exposed in the diamond mine itself.

As recent studies in various parts of the world on schists of doubtful character have proved that the schistose structure is not, as was long supposed, an unequivocal proof of a clastic origin, an attempt has recently been made to find in the rocks themselves internal evidence for or against the hypothesis of such an origin. As is well known, most of the mineralogical elements of a metamorphosed rock, whether clastic or otherwise, are authigenic; others which in certain cases may be presumed to be allothigenic may have been broken up, recrystallized, enlarged by secondary additions,[1] or etched, so that all traces of the original worn surface of clastic grains may have been lost or so obscured as not to be recognizable with certainty. The hopes of finding such internal evidence are therefore limited to the rare accessories, and among these practically to zircon, not only on account of its almost universal distribution in sedimentary deposits, but also of its resistance to chemical changes. In the examination of the heavy residues of a considerable number of the rocks of the series in question, it was found that in rocks of their character and degree of metamorphism, zircon is the only element that can be depended upon to give unequivocal evidence as to the mode of origin. All the other constituents, principal or accessory (quartz, mica, iron, and titanium oxides, tourmaline, disthene, etc.), present the fresh appearance of authigenic elements, as most of them doubtless are, though in some cases this appearance may be due to the fragmentation, regeneration, or etching of original clastic grains. On the contrary, the zircons in the considerable number of residues examined have failed to show evidence of secondary modification by any of the processes

[1] As will be shown elsewhere, tourmaline may be regenerated by secondary enlargement in the same manner as in the well-known case of quartz. A remarkably fresh appearance of the surfaces of quartz grains, due to etching, is noticeable in the washings from the clays of São João da Chapada, but it is to be presumed that this is a phenomenon of decomposition rather than of metamorphism.

mentioned so that, when present, their evidence is positive when they show distinct signs of wear, doubtful when these signs are absent or dubious.[1]

Applying the zircon test to the material at hand from the São João da Chapada mine the evidence for the clastic origin of the greater part of the original rock types from which the clays are derived has proved to be unexpectedly satisfactory. A number of samples of typical clays, including some reputed to be diamantiferous, afforded zircons which in abundance, size, and amount of wear, are comparable with those of the granular quartz rock (itacolumite) that occurs above the schists in the immediate vicinity of the mine. To judge from the number and character of the zircons, these samples represent original grits rather than more purely argillaceous material as was supposed from their present character and appearance. This conclusion is confirmed by the amount and size of the quartz grains (beautifully etched) that are also separated by the washing of the clay. In a miner's concentrate representing mixed material, fresh, prismatic glassy zircons occur mingled with the ordinary rounded, reddish clastic type indicating that other types of rock, presumably eruptive, may be represented among the clays. For the present discussion, however, the essential point is that the generality of the zircons of the clays are worn, thus confirming the assumption, based on stratigraphical evidence, that the clays of the mine represent a series of schists of which the predominant types are of clastic origin. This conclusion, however, does not exclude the possibility of subordinate intercalations,

[1] The rounding of the angles alone cannot be taken as an unequivocal sign of wear, as it is often an original feature of the zircons of undoubted eruptive rocks. When the angles are rounded by attrition the faces are also dulled in a manner that is readily distinguishable from that produced by malaconization. Undoubted clastics occur in which the signs of wear of the zircons are inappreciable, either because the amount of transportation has been too small or the material too fine to produce them, or because they have been involved in other elements, as in the case of arkose and tuffs. In the case of argillaceous rocks the rarity and minuteness of the zircons may be an argument in favor of a clastic origin even when they show no distinct signs of wear, but the evidence is not conclusive as they are minute and rare in some eruptives as well.

or injections, of eruptive origin, which, judging from evidence elsewhere, are rather to be expected than otherwise in a cutting like that of São João da Chapada. For the question of the genesis of the diamond this hypothesis is of prime importance and the evidence thus far available for or against it will now be examined.

Of the three diamond-bearing bodies described by Burton and Gorceix only two were seen by me. The masses shown me were displaced by landslides, but, as nearly as can be determined, they represent the middle and lower bodies of Burton.

The mass supposed to represent the lower body of Burton and the mottled clay of Gorciex consisted of a considerable rectangular block of quartz, with plates of specular iron, and with laminated clay representing the decomposed country rock adhering to it on one side. On the other side was a mass of friable structureless reddish clay, sharply defined on the side opposite the quartz from the harder laminated clay of the decomposed country rock, which is here also reddish, but of a different tint and aspect. The whole appearance of the mass was that of a vein with sharply defined walls, and it was so described on account of the quartz, though, as the earthy portion was referred to a decomposed rock of undetermined character, the term dike might have been employed with equal propriety. The earthy diamond-bearing mass was shown to consist of an argillaceous portion stained with iron oxide and a sandy portion with quartz and tourmaline. The heavy residue which has since been separated and examined consists principally of aggregations of specular iron and of a micaceous mineral representing some altered silicate with a great abundance of microscopic brown tourmaline. Yellowish, burr-like aggregates of anatase are also abundant, while rutile is comparatively rare, as are also grains of disthene. All of these minerals are evidently authigenic. The rare grains of zircon are in part distinctly worn, in part with the fresh appearance of an authigenic element. A few grains of staurolite also occur, and these are, for the most part, rounded, giving them a worn appearance, but as some of them are distinctly etched, it is thought that this aspect may be due to etching rather than to attrition. Unfortunately, it is not absolutely certain that the zircon and staurolite may not have been introduced from a foreign source, as at the time the washing was made the extreme care now found necessary to avoid admixture was not observed. On the assumption that the residue is a pure one (as it is believed to be),[1] the interpretation would be that the original vein material contained primary tourmaline and zircon with iron and titanium minerals that have furnished material for secondary hematite, anatase, and rutile, and that the accompanying schist contained clastic zircons, staurolite that is authigenic if the rounding of the grains can be attributed exclusively to etching, and disthene. The hypothesis that best suits these conditions is that of a granitic (pegmatitic) vein accompanied by phenomena of contact metamorphism.

The mass that was shown to me as representing the Barro Preto (black clay, middle body of Burton) had the characteristic of a bed rather than of a vein. The clay is well laminated, ribboned with fine regular alternating streaks of white and black, the latter composed mainly of a fine powder of hematite. The residue, freed from clay, shows a great abundance of black hematite, so finely divided that much of it floats away in the washing, a moderate amount of etched quartz, a small amount of tourmaline in coarser grains than in the body above described, and a comparative abundance of rolled zircons, which appear also to have been somewhat malaconized. The titanium minerals, rutile and anatase, are absent, or extremely rare. A sample subsequently received as representing the same body agrees substantially with the above, except in the greater abundance of quartz and the absence of tourmaline. All these indi-

[1] In the case of an admixture, rounded staurolites and fresh disthenes are not the minerals that might be expected to be introduced in the residue through lack of care in the preparation. Two or three grains of monazite were found that were certainly introduced by accident, but this very circumstance gives confidence in the general purity of the residue, as the much more abundant disthene and staurolite are not its usual associates.

cations point to an original bed of sandy ferruginous shale rather than to a vein.

The third body, not seen by me, is, according to both Burton and Grociex, characterized by a white feldspathic clay, kaolin, or lithomarge, with crystals of quartz and specular iron. Specimens exactly corresponding to this description were kindly furnished by Dr. Thomassi Bezzi, who collected them with the assistance of the owner of the mine, so that their authenticity is undoubted. Two specimens representing the Barro and the Duro mines are practically identical. In both a mass of snow-white, structureless clay, with nests of quartz crystals and specular iron, has adhering to it colored laminated clays. The contact between the two, sharply defined by the strongly contrasted coloration, is in part linear, in part irregularly undulated, but without appearance of graduation from one to the other. Irregular stringers of the white clay penetrate the mass of the colored, and irregular masses of the latter are inclosed on the former. The whole appearance of the contact is that of a vein or dike, represented by the white clay, with stringers and inclusions of the country rock. The contrast between the heavy residues of the two kinds of clay is as striking as that of their coloration and general appearance. Corresponding quantities taken at a distance of a few millimeters from each other or either side of the contact gave very different residues, both as regards quantity and mineral composition. That of the white clay is extremely small, consisting, aside from rare grains of quartz and specular iron that apparently come from segregations rather than from the body of the clay, exclusively of delicate needles of yellow rutile, the *Agulhas cor de ouro* (golden needles) mentioned by Burton. The residue from the colored clay is, on the contrary, abundant, consisting, after the separation of the quartz (beautifully etched) and iron oxide, of rolled zircons, anatase, tourmaline, and iron-stained earthy grains of rudely prismatic form that evidently represent a decomposed silicate, possibly staurolite. This last is a characteristic residue of a metamorphosed clastic rock, and as tourmaline and anatase seem to be present in abnormal abundance, contact metamorphism is strongly suggested. The residue of the white clay, on the other hand, gives no indication as to its origin, since the only characteristic accessory found in the small quantity available for washing is rutile, which is so widespread and varied in its mode of occurrence and association as to be indeterminative. One of the washings from the colored clay gave two types of zircons, the usual round, much worn reddish ones, and less worn whitish elongated prisms. The latter resemble those already mentioned as occurring (with a fresher appearance, however,) in a miner's concentrate, and still more closely those of a partially decomposed rock from the Sopa mine in the neighborhood (where lithomarge also occurs, but is not known to be diamantiferous), which strongly resembles the European "porphyroid," and is either metamorphosed arkose or porphyry, probably the former.

This white clay, in the character of its material and of its contacts, and in the lack of characteristic clastic elements, is strongly suggestive of the so-called pegmatite veins that are of frequent occurrence in similar formations and under similar conditions. The quartzose character of some of the veins, or parts of veins, is not inconsistent with this hypothesis, as the intimate relations and interdependence of quartz and pegmatite veins are well known. The indications furnished by this body are therefore in accord with those of No. 1—that is to say, that the vein matter was probably originally pegmatitic, and that it was accompanied by phenomena of contact metamorphism.

So far as can be made out from the observations thus far made on material the most unsatisfactory that can be imagined (foliated and highly modified by dynamometamorphism and afterwards totally decomposed so as to present, in its present state, one of the most intricate problems of mud geology), the most plausible hypothesis as regards the various clays of the São João da Chapada mine is that they represent an original group of phyllites of varied character, but principally, if not exclusively, of clastic origin, threaded with veins of pegmatite.

The possibility of an admixture of originally eruptive elements in the phyllites themselves is, as already noted, suggested by the supposed copper staining of Burton and also by the harder olive-green clay that he mentions as occurring with the second body. The only rock specimen that has come to hand from the mine is a small fragment of a sericitic schist that, aside from a very fine dust of hematite, gives no residue whatever, and which may be suspected to be a metamorphosed eruptive.

On the hypothesis of the original essentially pegmatitic character of the diamond-bearing bodies of São João da Chapada three important questions arise which can only be solved hypothetically. What was the original type of the pegmatite? Is it eruptive or secretionary? Do the diamonds belong to it or to the country rock in its immediate vicinity, and perhaps modified by it, or to both?

Bodies of pegmatite are quite common in the older rocks of Brazil, both in the diamond regions and elsewhere, occurring not only in the gneiss and granite, but in the schistose series as well. Those that have been examined are dike-like in their mode of occurrence and granitic in composition. They are almost universally decomposed, affording a pulverulent kaolin, not the indurated type of lithomarge. Their residues are usually abundant and typically granitic, representing more particularly the type of the muscovite granites, consisting of zircon, monazite, and almost invariably xenotime. All of these characteristics (which, however, may not be essential) are lacking in the supposed pegmatitic clay of São João da Chapada, in which only the presence of quartz is suggestive of granite affiliation. On the other hand, however, they are compared with great propriety by Gorceix with the topaz-bearing clays of Ouro Preto, and topaz is generally regarded as a granitic mineral. Topaz has not been reported from São João da Chapada, but in one washing from a mixed sample of the clays a minute grain was observed that in form, optical properties, and specific gravity seems to agree with that mineral. The other known types of pegmatite—those affiliated with syenites, diorites, and gabbros

— have not as yet been definitely identified in Brazil, though they doubtless occur. The apparent absence (or extreme rarity) of zircon may perhaps be taken as indicative of gabbro, and considerable masses of this type of rock, to which the supposed pegmatite might be referred as apophyses, are known to occur in the diamond region. So far as known, however, this is the utmost limit in the direction of basic rock types to which one can go, even hypothetically, in seeking the probable original type of this supposed pegmatite.

The question of the eruptive or secretionary origin of pegmatites has long been a subject of discussion among geologists, and eminent authorities can be cited in favor of either view. The recent studies of Lehmann, Brögger, Williams, Crosby, and others seem to have clearly established that most if not all of them are essentially eruptive masses, though possibly modified in some way by aqueous agencies. Even before becoming acquainted with the literature of the subject this view had seemed to me to be the only acceptable one as regards the typical pegmatites of Brazil. The extension of it to such problematic occurrences as the diamond-bearing bodies of São João da Chapada and the topaz-bearing bodies of Ouro Preto cannot as yet be fully established on account of the lack of complete studies in the field and the decomposed condition of the material. Aside from the general analogy that they present with typical pegmatites, nearly all the criteria given in the recent papers by Williams and Crosby and Fuller in support of the hypothesis of eruptive origin can be cited in favor of the same hypothesis as applied to these bodies. If, as is suspected, they present phenomena of contact metamorphism, a crucial test can be applied through the study of the heavy residues of the enclosing schists at different distances from the contact. This, however, involves field studies that for the present cannot be undertaken. As the case stands at present the hypothesis of an eruptive origin, though not fully proven, is by far the most probable.

The response to the third question is still more unsatisfactory than those to the other two. At the time of Burton's visit the most typical pegmatitic body was regarded as the richest of the Duro mine and in his description of the Barro mine he states that the white clay (called *diz*, or chalk, by the miners) served as a guide to the diamond formation. It is by no means certain, however, that the diamonds actually occurred in it rather than in the adjacent colored clays in contact with it and for which it serves as the most apparent guide. In the specimens at hand the part considered as the contact zone is mineralogically the richest, and it may be suspected that the diamonds occur in it rather than in the white clay. The lower body reputed to be the richest at the time of Gorceix's visit is, according to his description and that of Burton, much less decidedly pegmatitic in aspect and the part seen by me seemed to be a decomposed dike with no apparent suggestion of pegmatite. The part of this body indicated to me as diamantiferous belongs certainly to the supposed dike and not to the contact zone. The other body, the Barro Preto, seems, according to the descriptions and the part seen by me, to be a specialized layer of the phyllites the relations of which to the pegmatites (if it has any) are not clear. In short the question as to whether the diamond occurs at São João da Chapada exclusively in the supposed pegmatitic bodies, in the contact zone of said bodies, in layers of the phyllites more or less removed from such contact zones, or in all, must remain an open one.

As the case stands at present the indications seem to be rather in favor of the hypothesis of the formation of the diamond in the phyllites, the presumptive agent being the supposed eruptive which in some of its phases presents a pegmatitic character. This involves, presumably though perhaps not necessarily, the supply of the necessary carbon from the phyllites themselves, but as the series is known to include in many places graphitic members such a supply may reasonably be predicted at São João da Chapada. Moreover the evidence from Kimberley, where, according to Launay (*Les Diamants du Cap*), the rock considered rich only yields one part of diamond to 3 mil-

.ion to 36 million parts of rock, indicates that the amount required is so infinitely small that few rocks can be conceived that may not contain, in some form, the necessary supply of carbon. The amount of this element that presents itself in the form of carbonates in the decay of many rocks, that in their sound condition are not recognized as containing it in any form, is far in excess of that here indicated as necessary. In this connection it may be remarked that the hypothesis that attributes a preponderant importance in the genesis of the diamond to the carbonaceous shales of the upper part of the Kimberley section, is subject to the criticism of furnishing a preposterously enormous superabundance of raw material.

The three localities above discussed offer no certain indications of more than one mode of genesis of the diamond in Brazil. The occurrences at Grão Mogol and Sãn João da Chapada can very easily be brought into line on the hypothesis, which has much in its favor that at the former place the diamond is an allothigenic mineral derived from deposits similar to those at the latter. For São João da Chapada and Agua Suja the comparison presents no difficulty if the diamonds at the last place are assumed to come, as is quite possible, from the underlying schists. If, however, they are genetically related to the later eruptive series, the hypothesis of a substantially similar mode of genesis requires that the predominant factor be an eruptive rock, which may vary greatly in its mineralogical character and mode of occurrence.

As compared with the Kimberley occurrence that of São João da Chapada seems at first sight to be characterized by an almost absolute lack of analogies. Until quite recently the only known feature at Kimberley offering some remote resemblance to the Brazilian fields was the presence of a quartzite in the lower part of the section. This resemblance is somewhat increased by the later developments as metamorphic schists appear mingled with the quartzite in the lower levels of the deep shaft (see section on p. 137 of Launay's *Les Diamants du Cap*). For the present the information regarding these lower rocks is very meager, and further developments must be awaited to determine whether or not this resemblance has any special significance. Another point in common that may prove to be of greater significance than at first sight appears is the occurrence mentioned by Carvill Lewis[1] of tourmaline and disthene which seem to be formed by metamorphic action about inclosed fragments of schist. It is true that disthene is not a specially characteristic mineral at São João da Chapada, but it is extremely widespread and abundant in the schist series in which the mine is excavated, and of the aluminous silicates, is the most constant and characteristic of the associates of the diamond in the Brazilian alluvial washings. The significance, if any, of its persistent association with the diamond (now verified at Kimberley) is that of a mineral characteristic of the metamorphism (by contact or otherwise) of argillaceous rocks.

In order to bring the Kimberley and Brazilian mode of occurrence into line as phases of a single mode of genesis, it seems necessary to put aside the idea that the recent interesting experiments on the artificial production of the diamond afford a solution of its terrestrial origin, and that the Kimberley type of rock and mode of occurrence are essential features. Presumably also the genesis must be sought in the rocks affected by the eruptive masses rather than in those masses themselves. There are still many obscure points about both places, and until these are cleared up no satisfactory comparison can be made. At São João da Chapada there is little prospect of working being resumed so that no additional light is to be expected from there, but at Kimberley the workings may ultimately reach a depth that will give a complete solution of the problem for that place and mode of occurrence. When this occurs, if it is verified that the ultra basic type of eruptive rock, brecciated structure, and slot-like mode of occurrence are necessary features, the Brazilian occurrences must be put into another category.

ORVILLE A. DERBY.

SÃO PAULO, November 29, 1897.

[1] Papers and notes on the genesis of the diamond.

THE GLACIATION OF NORTH CENTRAL CANADA.[1]

I WISH very briefly to place before you a statement of what would seem to me to have been the conditions that prevailed during at least part of the glacial period in the great Central Plains region of Canada, but before going farther I take great pleasure in acknowledging my indebtedness to Professor Chamberlin, Mr. Warren Upham, and many other glacial geologists of the United States, whose work is so closely connected with mine, and who have so clearly expounded many of the principles on which my explanations are based. It is an especial satisfaction to me to feel that the results of my investigations accord so well with theirs.

In the preparation of the slides here shown I have freely used the published works of these geologists, and of Dr. Dawson and Messrs. McConnell, Low, and of our own geological survey, when depicting the conditions that prevailed in those portions of the country which have not come under my own personal observation.

That portion of Canada, to which I propose to refer for a few moments, lies between west longitudes 85° and 130°, and north latitudes 49° and 69°; or perhaps it may be more intelligibly located as being bounded on the east by the west coast of Hudson Bay, and a prolongation of the same line southward, and on the west by the Rocky Mountains, the average distance between these two lines being about 1100 miles; on the south by the international boundary, and on the north by the Arctic Ocean, which are an average distance apart of 1400 miles, giving a total area of about 1,500,000 square miles.

This vast region has a remarkably even surface contour, with a mean elevation above the sea of about 1200 feet, and slopes gently from the foot of the Rocky Mountains northeastward to

[1] Read at the Toronto meeting of the British Association, August 1897.

Hudson Bay. The contour lines here shown are respectively 600, 1500, and 3000 feet above the sea, and from the 3000 feet contour line the surface has an average slope of a little less than three feet to the mile. This slope is of course not quite regular, being broken by hills and valleys, and occasionally the country rises for some considerable distance in the opposite direction, but on the whole the general decline is very well marked, and no high mountains break the general monotony of the landscape.

In the more northern portion of the region are the treeless plains, or "Barren Lands," extensive level or undulating grassy plains, with a mean summer temperature below 50° F., and with a frozen subsoil which prevents the growth of trees. South of this is the great forest region, the home of the chief fur-bearing animals of Canada, and still farther south are the plains or prairies, which many of you will probably cross on the transcontinental railways after the close of this meeting.

It would be beyond the scope of this paper to discuss the question of rainfall, but suffice it to say that the humidity of the atmosphere decreases from the seacoast inland, and while the Barren Lands are kept constantly wet by fogs and drizzling rains, the air over the prairies is very dry, and licks up rapidly any moisture that may be lying on the surface of the ground.

As you will see from the handbooks prepared for the use of the members of the association, the northeastern part of this region is underlain by crumpled and distorted Archæan rocks, whose surface has, even in pre-Cambrian times, been reduced to an undulating plain, with very slightly accentuated contours. On each side of this elongated area, or low central ridge, of highly altered Archæan rocks, are flat-lying limestones, sandstones, and shales, varying in age from the Cambrian up to the Tertiary, and separated by several erosion intervals, which, with the water-deposited strata, would indicate a gradual rising and lowering of the land along a line parallel to the present Archæan outcrop. From a study of the Rocky Mountains, and the mountainous region of British Columbia,[1] Dr. Dawson has shown rea-

[1] On the Later Physiographical Geology of the Rocky Mountain Region in Can-

sons to believe that the oscillations of the land were exceptionally rapid in early glacial and immediately preglacial times. But it would seem probable that the drainage has always followed the main valleys which still trench the surface, running more or less at right angles to the mountains.

The pre-Cambrian valley of Chesterfield Inlet, extending eastward towards Hudson Strait, and westward towards Great Slave Lake, and the post-Cretaceous valley of the Saskatchewan, extending towards the lower valley of the lower Nelson River, and many other valleys running more or less parallel to these, go to prove the general correctness of this statement.

In the opinion of the writer almost all of this country was overspread by the Keewatin glacier, which centered in what is now the comparatively low country west of Hudson Bay. Evidences of its presence may be seen almost everywhere in striated rock surfaces, giant's kettles, widespreading sheets of unstratified till, stratified inter-till deposits, moraines, eskers, and transported bowlders.

The causes of the great cold of the glacial epoch are yet enshrouded in mystery, and the most that has been suggested is that if such and such things had been so, if the land had been higher here or lower there, ice would have accumulated in northern latitudes, but as yet there is little or no proof that such conditions did exist. At present it would appear to be much more satisfactory to spend our energies in endeavoring to follow up the traces left by the glaciers and lakes of the glacial epoch, and to first determine the conditions that existed at one time, or the order in which certain conditions existed, rather than to devise elaborate theories to account for conditions that may never have occurred. When the country has been thoroughly examined, and the glacial deposits, striæ, etc., are well known, the proximate causes of these phenomena will in all probability be easily determined.

The information with regard to the conditions of glaciation

ada, by George M. Dawson, Trans. Roy. Soc. Can., Vol. VIII, Sec. 4, pp. 1–74. Ottawa, 1890.

unearthed is undoubtedly but a very small portion of what will be known when our country is more fully explored, for compared to the vastness of the field and the probable extent of the harvest of knowledge, the harvesters are indeed very few. The observations here discussed have been made by the writer during the past thirteen years, but as individual records are difficult to grasp and remember, I have attempted to connect them in such a way, and to bring them graphically before you, so that you may form a clear idea of the results that have been attained, and at the same time I shall endeavor to state very briefly some of the evidence on which those results have been based, so that you may distinguish between the records and the connecting theories.

Up to the present time three great continental glaciers have been recognized in Canada, viz., the Cordilleran, which covered the western mountains and their intervening plains, from latitude 49° to latitude 66°; the Keewatin, which covered the great plains east of the mountains; and the Labradorean, which spread over northeastern America from a center in Labrador.

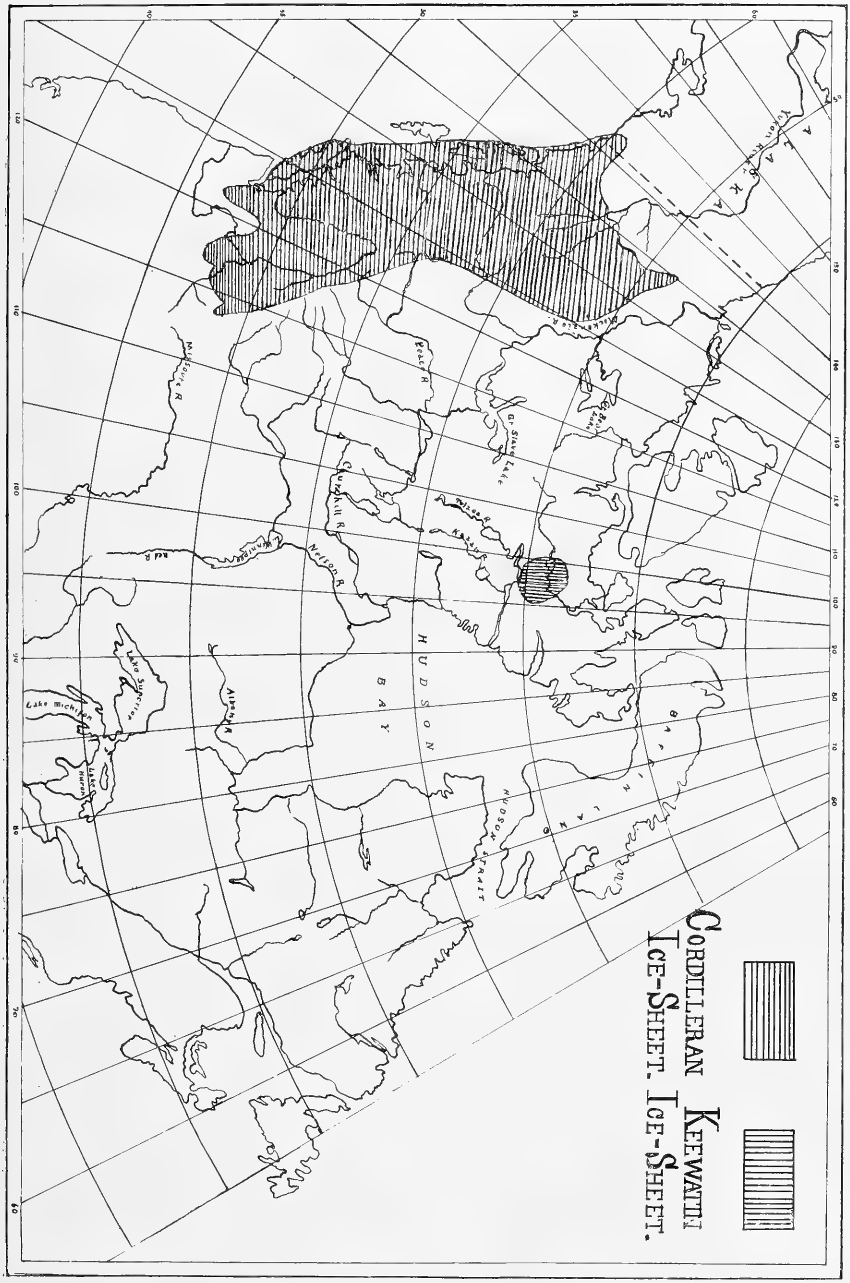
The earliest till as yet recognized in Western Canada, east of the Rockies, has been called by Dr. Dawson the Albertan Deposit,[1] and has been shown by him to have been formed by tongues of the Cordilleran glacier, which extended outwards towards the plains through the transverse valleys of the Rocky Mountains.

The illustration shows the greatest extent of this Cordilleran glacier as defined by Dr. Dawson.

From the fronts of these glacial tongues streams rushed eastward, carrying with them large quantities of coarse detritus which were soon deposited in the bottoms of the valleys as beds of coarse, well-rounded gravel, called by Mr. McConnell the Saskatchewan gravel, this gravel and the Albertan till being directly traceable into each other.

The Cordilleran glacier then withdrew; but whether it entirely

[1] Glacial Deposits of Southwestern Alberta, by GEORGE M. DAWSON and R. G. MCCONNELL, Bull. Geol. Soc. Am., Vol. VII, p. 66, Rochester, 1895.


Cordilleran Ice-Sheet.
Keewatin Ice-Sheet.
Hudson Bay
Hudson Strait
Lake Superior
Lake Michigan
Lake Huron
Nelson R.
Churchill R
Peace R
Missouri R
Gr. Slave Lake
Alaska

disappeared, or merely confined itself to the west side of the Rocky Mountains, I do not know, but at all events it seems to have ceased to be an important element in molding the features of the plains.

After the withdrawal (or possible disappearance) of the Cordilleran glacier, the Keewatin glacier overspread the country, radiating outwards from a center probably lying somewhere between Doobaunt and Back rivers. The till formed during this period, which is probably synchronous with that of the sub-Aftonian period of Professor Chamberlin, may be easily recognized in the scarped banks of many of the streams in Alberta, where it overlies the Saskatchewan gravel of the Albertan period. It is composed largely of material derived from the underlying Cretaceous and Laramie rocks, but at the same time it contains a considerable quantity of other material transported from a distance, some of which, consisting of granite, gneiss, quartzite, and similar rocks, has been derived from the Archæan nucleus to the northeast, while some has been derived from the Cambrian sandstones, and Cambro-Silurian and Silurian limestones that extend around the edge of the Archæan.

After the deposition of the sub-Aftonian till the Aftonian period of deglaciation set in, during which the Keewatin glacier became greatly diminished, and interglacial deposits were laid down, both in extraglacial lakes, and in lakes and swamps at some distance from the face of the glacier. How far the foot of the glacier withdrew in this interglacial time I do not know, but I am inclined to think that most of Manitoba still remained covered with ice, for in the western part of that province I have not been able to find evidence of more than one main Keewatin interglacial period, which is probably later than the Aftonian period.

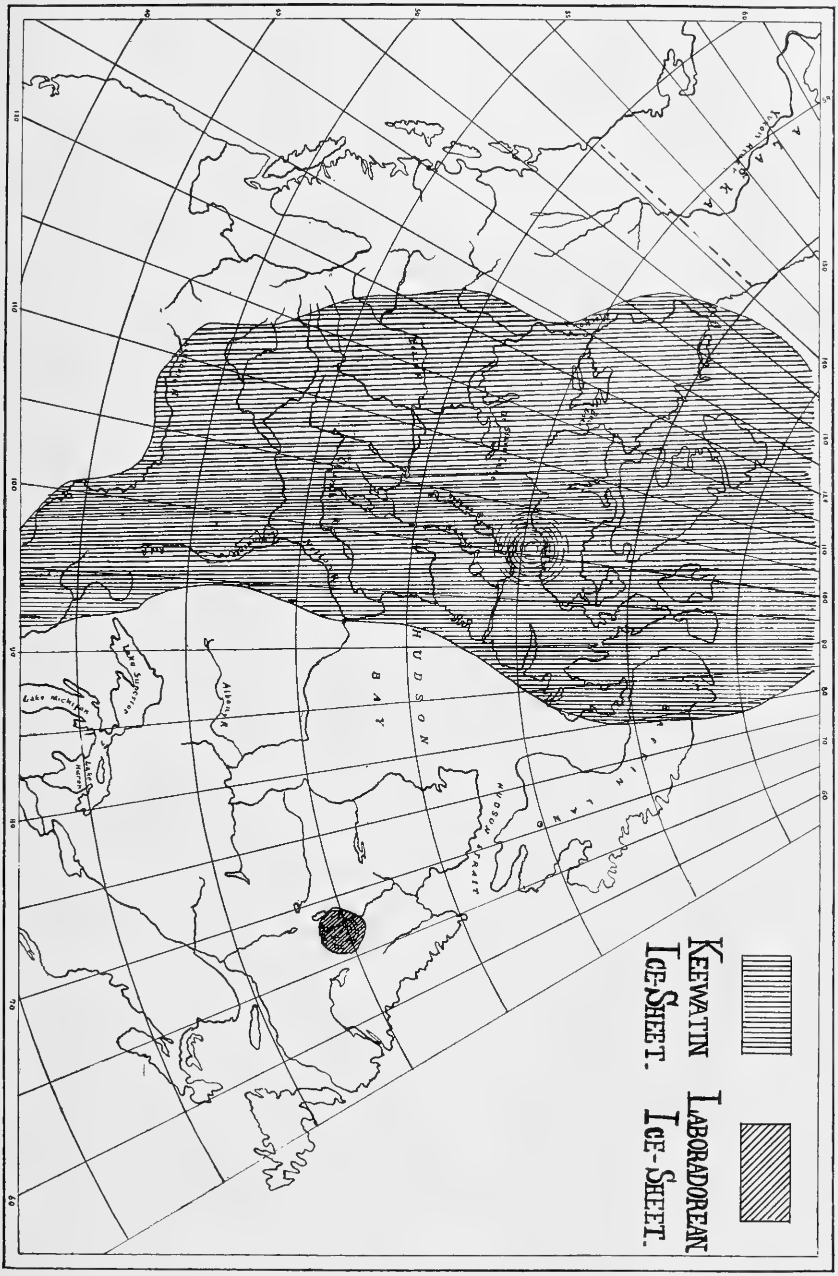
After this period of diminution the Keewatin glacier again began to increase, and it spread southward and westward until it had reached about the same limits that it had reached during the sub-Aftonian period, and had spread another sheet of till over the earlier till and subsequent interglacial deposits. The period of this advance of the ice would seem to correspond to the Kansan epoch, as at present understood by American geologists. This till is very similar to that below it, but the material of which it is composed is more highly oxidized and decayed, and fragments of soft, brittle rocks, such as lignite, are much less common in it than in the lower till.

Both during the Kansan and sub-Aftonian epochs, extraglacial lakes of greater or less size doubtless existed, and any material brought down into them by the glaciers would doubtless have been scattered over their floors or along their sides. Thus bowlders were probably carried some distance beyond the extreme limits to which the glaciers themselves reached, as, for instance, on some of the terraces near, and at the foot of the Rocky Mountains where Dr. Dawson has recorded the occurrence of numerous transported bowlders. Where these lakes existed terminal moraines would also not be found, and thus the absence of terminal moraines may often be explained in places where we should otherwise expect to find them.

Striæ have not been recognized in this western district, for the soft Cretaceous rocks are not suitable for their preservation, but the older and harder rocks, nearer the center of the glaciated area, are everywhere scored with glacial markings. Around the periphery of this area underlain by harder rocks I have not been able to recognize more than one set of striæ referable to the Keewatin ice-sheet or rather more than one direction of striation, but nearer the glacial center several sets may be distinctly seen. Along the Doobaunt River above the Forks the oldest of these point southward, probably running outwards from a center between Doobaunt and Back rivers. These I have associated with the earlier stages of the Keewatin glacier, though I have no direct evidence to offer on that point, except that they are the earliest of four different and distinct sets of glacial striæ.

The accomplished geologists who have worked in the United States, near the headwaters of the Mississippi River, have found that there was an extended epoch of deglaciation after the deposition of the Kansan till, and I would assign to this interglacial epoch a line of division in the till of western Manitoba, along which stratified deposits may occasionally be seen, but which is strongly marked in several places by beds of bowlders that have been sunk in the surface of the earlier till, and being there held firmly in place have been smoothed and striated by the later glacier which passed over them. How far the Keewatin glacier retreated during this second epoch of deglaciation is not known, but it is not improbable that it withdrew far north of the present northern boundary of Manitoba.

After this interglacial epoch the Keewatin glacier again began to increase, though its center of dispersion had gradually shifted southeastward until it now rested over the country between Doobaunt and Kazan rivers. From this center it flowed outwards in all directions, and its striæ may be seen on most of the rocky knolls throughout that whole northern country, running southward towards Lake Winnipeg, westward towards the Mackenzie River, northward towards the Arctic ocean, and eastward towards Hudson Bay. Everywhere the smooth-faced hills give evidence of its presence, and even in the absence of striæ, the evenly-rounded surfaces facing the glacial center, and the broken, craggy hills looking in the opposite direction, furnish convincing evidence of the direction of flow of the ice. As the glacier advanced southward it came in contact with the high escarpment of Cretaceous shales forming the Porcupine and Duck mountains in Manitoba, and part of it was diverted to the east of south along the great valley of Lake Winnipeg. This lobe appears to have extended southward into Minnesota, Dakota, and Iowa, and to have deposited a till which probably corresponds to what Professor Chamberlin has called the East Iowan Formation. The Palæozoic limestones of western Manitoba have been beautifully scored by the markings of this glacier, and its grooves and striæ were detected in many places around the shores of Lake Winnipeg. East of the shores of Lake Winnipeg the exposed surfaces of the Archæan rocks were carefully searched for this set of markings, but none could be detected. It therefore seems probable that the eastern edge of this lobe or portion of


KEEWATIN ICE-SHEET.
LABORADOREAN ICE-SHEET.
HUDSON BAY
HUDSON STRAIT
Lake Superior
Lake Michigan

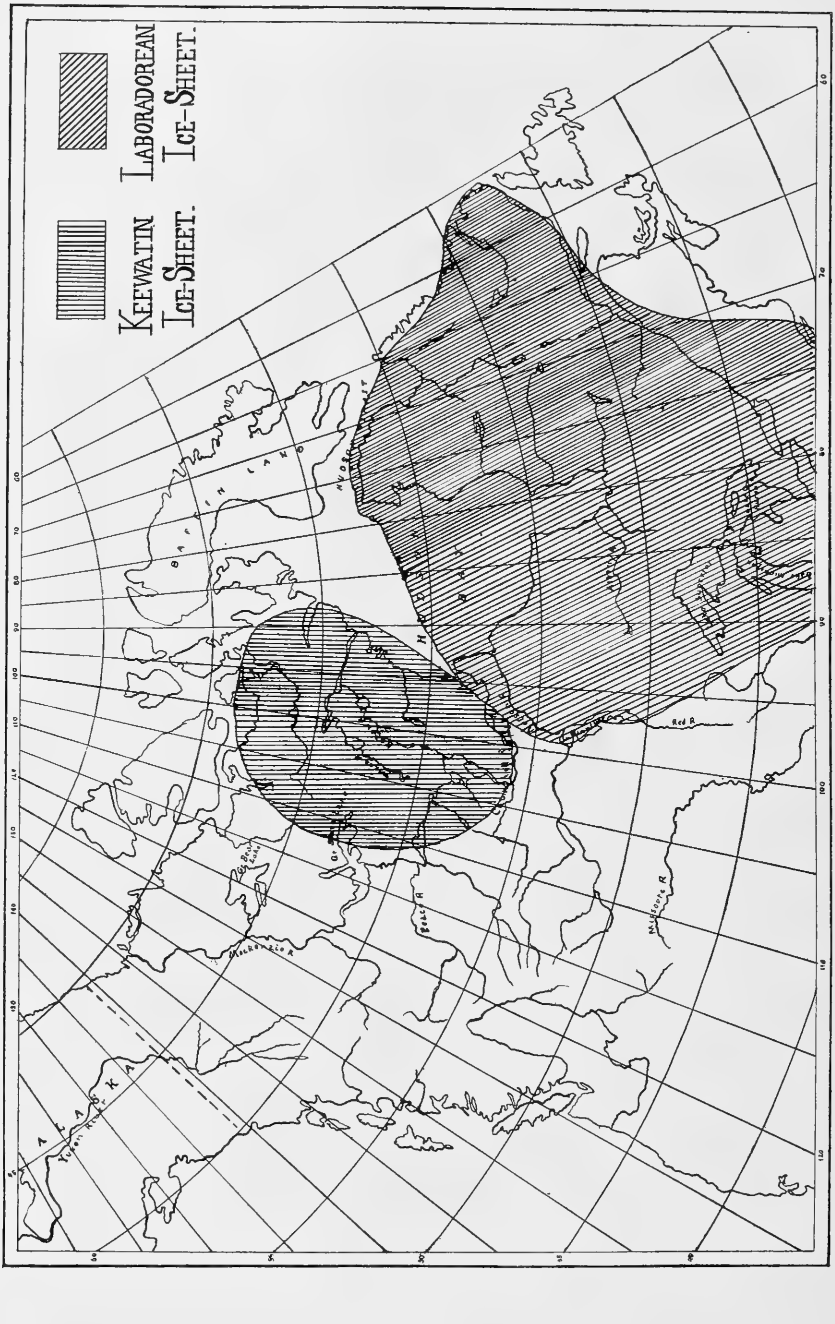
the Keewatin glacier did not extend very far east of the present eastern shore of Lake Winnipeg, and it is also probable that throughout its advance there was a free drainage eastward into Hudson Bay.

Traces of the existence of the streams that flowed eastward from the face or side of this glacier were found in several places in the form of deep potholes or giant's kettles, excavated in the summits or on the eastern slopes of knolls of granite, and gneiss where they could not have been formed under present conditions. At one place, on the south side of Berens River, several of these potholes occur on the east side of a granite knoll, one of them, at least, being ten feet in depth, and about thirty inches in diameter from top to bottom. The ten-foot hole was cleaned out, and was found to contain a great many rounded pebbles, all of Archæan rocks, some similar to the rocks of the surrounding country, and others that had evidently been transported from a distance. Both this and most of the other rocky hills where potholes were seen, have been scored and scraped down by the later glacier from the east, the outer sides of some of the holes having been cut away, leaving rounded niches in the faces of the smooth hillsides.

While a portion of the Keewatin glacier flowed southward in the Winnipeg basin, another parallel glacial stream would seem to have traveled southward between the Porcupine and Duck mountains on the east, and the rising land now marked by the Missouri Coteau on the west, both sides of this wide shallow depression being now at elevations of about 2200 feet above the sea. This glacial lobe probably extended southward into Dakota, and at its greatest extension it coalesced with the Winnipeg lobe over the summits of the Porcupine and Duck mountains, but for long periods, doubtless when the glacier was both advancing and retiring, the two lobes were more or less separated, and an extensive interlobate moraine was deposited on the summits of these hills. The Missouri Coteau is also considered to be the great moraine deposited along the west side of this lobe of the Keewatin glacier. Whether the glacier extended west of the Missouri Coteau during this period is uncertain, but there is a strong morainic ridge extending from the Hand Hills northwestward by Sullivan Lake to the Beaver Hills, which may have been formed at this time. A high, stony, lumpy ridge about the same elevation as the Missouri Coteau, and north of and more or less parallel to the Saskatchewan River, between it and the Beaver and Athabasca rivers was doubtless formed a little later in the same glacial epoch.

Now, confining our attention to the Winnipeg lobe of the Keewatin glacier we find that after reaching its greatest extent in a southeasterly direction it gradually retired northward, and as it retired a portion of the Laurentide glacier which had accumulated in the country farther east, perhaps on the high land of the Labrador peninsula, advanced and the fronts of the two united. The Keewatin glacier had probably retired well north into Manitoba, and possibly beyond the northern confines of that province, before it was joined by the eastern glacier. After they had united the water formed by the melting of the two glaciers was ponded between their fronts and the high land to the south and west, and a large extraglacial lake was formed, which has been called by Mr. Upham Lake Agassiz.

As the Keewatin glacier retired still farther, the eastern portion of the Labradorean glacier continued to advance and obliterated most of the marks left by its predecessor, but here and there, on the harder rocks on the east side of Lake Winnipeg and farther north, distinct cross striæ were observed, where the later glacier had not rubbed out all the earlier grooves and striæ. The later glacier reached to the west side of Lake Winnipeg, or in some places a little beyond, its front assuming a roughly lobate form. Near the mouth of the Saskatchewan River the till formed by both glaciers is well shown, but between the two is a thickness of 12 feet of stratified sand and clay, showing that the Keewatin glacier had retired northward for a sufficiently long time before the advent of the Labradorean glacier to allow of the deposition of this thickness of water-lain lake-deposits.


Keewatin Ice-Sheet.
Laboradorean Ice-Sheet.
Baffin Land
Hudson Bay
Alaska
Mackenzie R
Red R.
Missouri R

Two hundred miles still farther north, along the Grass and Burntwood rivers, the striæ of the two glaciers cross almost at right angles to each other, the one being clearly later than, and independent of, the other. A little farther east, north of Gull Lake and Nelson River, is a long narrow sandy esker, from 90 to 200 feet in height, running east and west, clearly formed by one of the streams draining the Labradorean glacier. This ridge of loose sand would certainly have been swept away, if any glacier had advanced from the north subsequent to its formation.

Before the fronts of the two great glaciers had separated the eastern one had again begun to retire, and as it retired a thickness of from 50 to 100 feet of stratified clays and silts were deposited in the bed of Lake Agassiz, chiefly north of the present basin of Lake Winnipeg, for there some large streams draining the Labradorean glacier discharged into the lake, bringing with them a heavy cargo of glacial mud. The positions of these streams are still marked by long and high eskers, which may be seen near the banks of the Nelson River, crossing the country in a direction parallel to the later striation.

The Nelson River, in its northern course, from Playgreen Lake to Split Lake, marks the approximate eastern limit of this deposit of stratified clay, and along the eastern shores of Lake Winnipeg the stratified clays were not found at a greater height than 150 feet above that lake, and, except at one place, at no great distance back from its shore.

The absence of these stratified deposits would tend to show that the eastern glacier had not retired to any considerable distance east of Nelson River and Lake Winnipeg, before Lake Agassiz was drained by the gradual shrinkage of the Keewatin glacier to a small area in the vicinity of Doobaunt and Yath-kyed lakes.

Subsequently the Keewatin glacier appears to have broken into two or more smaller glaciers, the centers of which lay still nearer the coast of Hudson Bay than the center of the single glacier. One of these centers rested over the hills southeast of Yath-kyed Lake, and from it the ice radiated in all directions, while another probably rested over the country north of Baker Lake and Chesterfield Inlet. Even at the present day it would take but a slight reduction in temperature, or a slightly greater precipitation, to cause that northern country to be covered with snow, for in the middle of August heavy patches of snow were seen resting on many of the hillsides and Doobaunt Lake was almost completely covered with a thick sheet of ice.

After the glaciers had been greatly reduced, or had entirely disappeared, the land west of Hudson Bay stood about 500 or 600 feet below its present level, and subsequently it gradually rose until it reached its present condition of comparative stability.

Whether the three great glaciers here referred to, namely, the Cordilleran, the Keewatin and the Labradorean, originated at the same time or not I do not know, and whether they waited for one another's disappearance or not I do not know; but this much appears certain that the Cordilleran glacier had reached its greatest extent and had retired, before the Keewatin glacier reached its extreme western limit; and that the Keewatin glacier, after covering the Plains region of central Canada for a great length of time, had retired a long distance toward its central gathering ground, before the Labradorean glacier reached its utmost western limit, and that it had shrunk to a very meager representative of its former greatness, when the latter glacier was still of magnificent propositions.

J. Burr Tyrrell.

THE USE OF LOCAL NAMES IN GEOLOGY.

No field of knowledge has ever experienced in the same short period, such a rapid expansion as have the geological sciences in these closing years of the nineteenth century. With this unparalleled advancement of modern geology, occasioned by the changes in fundamental conceptions, and the application of more refined methods of investigation, there has appeared, in every branch, an endless multitude of new and often seemingly useless names. The dropping of the old and familiar terms, the change in meaning of those retained, and the introduction of an unheard-of host of others, has brought forth long and emphatic protests against such innovations.

Many of these protests are not untimely. They come not alone from the layman, but from teachers and specialists. Everyone, who has come in contact with those not specialists, knows that the vast mass of technical terms and the cumbersome verbiage that is everywhere met with in the natural sciences are most disheartening features to the student, and at once raise well-nigh unsurmountable barriers to those who would only be too glad to take up such subjects. To the adoption of an elaborate terminology in any science this phase of the subject presents an obstacle more serious than all others combined.

The whole question is one that cannot be decided by discussion, no matter how able may be the arguments presented on either side. It is not whether the old terms alone are to be used in place of the free and unlimited coinage of new ones at a ratio perhaps of 16 poor ones to 1 good one, but whether from the very nature of the attendant conditions, the adoption of either plan is feasible. It seems not. As long as any branch of science lasts the specialists in that department will continue to introduce new terms to denote new conceptions and to make definitions more precise. In spite of all that others can do, changes in terminology will go on unabated. Protest is of no avail. A refusal on the part of the general scientific public to understand or to use the new names cannot prevent their adoption. Such action merely sets the majority outside the realm of influence. It is the specialist who sets the pace in nomenclature; others must keep up or drop out entirely. There is no other choice.

Protests against the use of new scientific names are really aimed at the unnecessary terms. In all of these protests there is almost invariably a failure to distinguish between two very different classes of terms. On the one hand the launching of new names is accompanied by a conscientious desire to better the condition of a science by clothing with suitable words the new ideas; on the other hand there is what a recent writer has aptly called a "prevalent and apparently incurable form of mania which busies itself in burdening science with a useless and formidable terminology." The first cannot be too highly commended, nor the second too deeply deplored. To be sure, it is not always possible for one not thoroughly up in a particular department to clearly discern, except in a few cases, the useful or the useless. Time alone can determine. Every progressing science must finally discard all of those titles that have served their purpose. It must also be prepared to receive all of the new ones demanded. Indeed, the rapidity with which a science is advancing is measurable, with but small degree of error, by the number of useful terms that are being proposed.

Much as it is to be deplored, it is nevertheless a fact that the mill from which the large and indifferent grist of new names is continually streaming is not wholly in the hands of those best qualified to manage it. From the very nature of the case there must ever be in its running almost no control. The real factor rendering the mighty host of unfamiliar titles so appalling is that a very large proportion of all of the new names published in the various sciences are proposed by those who are least fitted for the task. The great burden which the literature of a science must carry is the work of amateurs or those who are incapacitated for real scientific work, but fancy that knowledge is advanced, or a new science is founded when they let loose a flood of odd names upon the unoffending world. The inundation is more disastrous in some other departments of science than geology, but among the geological branches it is most apparent, perhaps, in palæontology, where the majority of the names catalogued are spurious.

Fortunately for everybody concerned there is a remedy for the evil that is as divine in its effect as was the discovery of ether in alleviating the physical sufferings of mankind. There is an immutable law that determines the perpetuation of scientific terms, regardless of the quality or of the countless myriads proposed. It is the same law that governs in literature, life and all else—the survival of the fittest. It makes no difference what the new terms are, or where they apply. If they are appropriate, useful and expressive they will last—but not fixed or for all time, only until they have fulfilled their mission, until others more harmonious with the ever-changing conditions take their places. If the proposed titles fail to meet a long felt want they are at once dropped, and forever forgotten. Which, among the new terms proposed, are the really useful ones, the ones destined to survive a while, and which the unnecessary ones doomed to perish at their birth, no man can tell. Moreover, it is absolutely beyond the power of its author, or of any other person, to say which names shall be perpetuated and which shall not. Every new term depends for its life not on the wish of its originator but on its own merit. It goes for what it is worth. With the many others it takes its chances. The final tribunal is the scientific public.

In the application of technical titles neither of the two extremes, too many or too few terms, is desirable. It is not advisable, if the best interests of geological science are to be considered, to adopt by itself either a rigid, unchangeable, and spare system of nomenclature, or one in which there is ponderous verbiage. The proper mean can be reached only after the long and fierce struggle for existence is over. The adoption of a terminology modeled according to the first extreme, inflexible and unchanging, manifestly can never meet the wants of a growing science. The establishment of such an arbitrary system could be defensible only in the case of a dead subject—a condition that no geologist is willing to admit for his science. Much as simplicity of statement should be sought it is not always possible, nor is it always desirable, that it should be followed at the expense of precision and easy understanding.

On the other hand, a scheme built upon the plan of the second extreme is less likely to be tolerated than the first. What is gained in terseness and exactness may be wholly lost in other directions. The new-born terms become mere symbols, perfectly meaningless and useless to all except the author. There is great danger of producing exactly the opposite effect from that intended. Instead of a beautiful fabric, the wonder and admiration of all, there is merely a lifeless, shapeless mass, shunned by many, cared for by none.

There is another phase of the question about which exists much confusion. Little mention is ever made of the twofold field of usefulness for which every science is designed; and in none is a dual conception more important than in geology. The one phase requires a terminology that is technical and special, that is established primarily for the active investigator and that is in no way intended to be memorized by the layman or any others, or to reach outside of a small and select circle. There will always exist a need for some such terms and the terms will always come in reponse to the need. No amount of protest will frighten the specialist out of using them. It may clutter up the scientific literature; it may be the bugbear of workers in closely allied branches of science; it may divert the attention of many from the subject itself. No matter. It has come to stay.

The other field demands names that are general, popular, simple, and free from technical appearance. The literature thus established is intended for an entirely different class from that which the first category takes into consideration. This distinction is rarely made, yet no one can doubt the existence of two wholly different audiences. In the presentation of every discourse the latter cannot be for both. It must be one or the other. It is the inalienable right of every author and every lecturer to select his audience. No one wishing to reach the many would think for a moment, of letting loose on his listeners or readers a flood of absurd and meaningless technicalities ; nor would a small, selected group of specialists wade through unknown depths of "simple" verbiage.

The coining of new terms to designate new ideas or more precise definitions has a bearing still broader than any yet considered in any of the numerous protests that have been presented. The layman complains of the host of "long names" with which every branch of science abounds ; the scientist criticises the terminology employed in the various branches other than his own ; the specialist bemoans the deplorable condition of the nomenclature in all branches as well as his own. Now, so far as the question under consideration is concerned, all are on identically the same plane. When a reason for this is sought only one stands out permanently. Each critic is, in reality knocking loudly for admission to other departments, without the same hard work and training that he has bestowed upon his own. Moreover, the protests against the established terminology are all one way ; were they not, the opposite view would not be so totally obscured. The demands for transfer from one department to another is invariably from the more simple and general to the more complex and special. Why the layman should desire to leave his own field to enter the domains of science unknown to him is as inexplicable as why a stratigraphical geologist should want to become a geographer or petrographer, or *vice versa*. Seldom does a scientist think of becoming an artisan. Yet if he should desire to do so, he would be, after five minutes' talk with a machinist, carpenter, or electrician, confronted by so many unfamiliar terms — technical terms of every day use — that he would at once cry out for greater simplicity of language. In the rapidly advancing branch of applied electrical science, for example, new terms are constantly appearing. The reason that these technical names are so difficult to understand is that each is an epitomized history of the special part, its position and function in the complete mechanism.

In the geological sciences the technicalities play the same rôle as they do in the arts and in business. To the large majority of people the name Monadnock, for instance, may mean only a big building, a war ship, or an Indian, but to the professional geographer it has attached to it a special meaning In a single word it sums up the complete life history of a particular kind of relief feature — a history that would require the space of a long chapter to describe in "simple" language every time it is referred to. If such a term chance to be a happy choice, if it save the busy worker the writing of several pages in order to express the same idea in another way, or "if it prove to be acceptable to workers in its field," as its author says, "it will take root and flourish; if not, it will soon wither away and be seen no more."

Granite, trap and greenstone, may be good enough "simple" names to apply to certain rocks, but the terms have become so general that in exact work they now mean almost nothing. To the petrographer the name pegmatite at once suggests a variety of granite that has a long and intricate history, totally different from dozens of other kinds of granite, each having a record equally complicated and equally diverse. This term incorporates in three short syllables history enough to fill a large volume. But he who wishes to know something about this particular kind of granite called pegmatite, little cares to waste his time in going over the whole literature of granite that he may get a little of the desired information. Likewise, who will not say that such a name as websterite, applied to a dark colored trap-like rock, does not at once separate the mass from a hundred other stony aggregates having a similar general appearance, and at the same time indicate a whole train of important events that would be otherwise passed over if the more popular name of trap were used alone. It may be argued that these are useful and necessary new names. Yet who could pass judgment on them until after they were proposed? And who can pass judgment on any terms until they are suggested? Or who can say whether they would be useful or not until they are tried?

In this day and age the geological sciences are protected at the start by one great safeguard against the promiscuous introduction of new names. There is one test that every new name must stand before it can venture to ask for recognition. This is the test of definition. Every new name in geology must be properly defined before it can be noticed at all. Its subsequent career depends upon its utility.

It has been already intimated that the rate with which a science is advancing is measurable by the number of new and useful terms that appear. At present this statement is especially true of some of the geological sciences. To be sure, new terminology does not necessarily indicate new facts, but when new terms receive the favor of those best qualified to pass judgment upon them, of the specialists in the particular department, when also these names stand for new conceptions, the branch of knowledge thus affected is certainly undergoing such radical change that the final outcome must be essentially very different from the old. This rapid change in terminology is at present characteristic of several of the branches of geology.

In no department has the coining of new names gone on more vigorously than in stratigraphical geology. The reason is to be found partly in the inherent conditions existing in this field, and partly in the complete change of base that this branch of the science has undergone in late years. The fundamental conception of the geological formation, whether large or small, whether a single bed or a great series, is a sharply defined "geological unit," instead of a vaguely bounded "group" of layers. The former is now capable of being clearly demarcated by strictly physical characters, that are the direct outgrowths of the actual conditions giving rise to the formations themselves; the latter is too often based upon trivial or accidental characters which are relatively unimportant as critical criteria, either in classification or correlation.

The principle underlying the recent naming of geological formations gives to each stratigraphical unit a special geographic designation, derived from some prominent town, watercourse or land form, within the boundaries of that formation. As thus established the latter is a well-defined and independent unit, having a definite place in the general geological scheme, no matter how this may change afterward, or what method of classification may be followed. This definite stratigraphical unit contrasts strangely with the unwieldy, ill-defined and usually little understood large formation of the past, the very name of which indicated either lack of exact knowledge of it itself, or a covering up of ignorance regarding its affinities. By this new method, or if it be more exact, by the vigorous application of an old principle that was so loosely followed as to be almost unrecognizable, geological nomenclature has been certainly greatly increased, even enormously enlarged by the introduction of the new plan. The former list of names numbered only about two score, indicating all of the smallest subdivisions which went to make up the general geological column. The names of the new list run up into the hundreds and even thousands, are different in every considerable area, and additions are constantly being made.

It is against this copious multiplication of geological names that the protests have been chiefly made. Curiously enough the struggle has been reduced to a clash between the practical field geologist on the one hand, and on the other the laboratory worker, those especially interested in the other departments than stratigraphy and the palæontologists, who see their standard classification abandoned, and their usefulness in the domains of geology diminished. And the former have won.

When, a decade and a half ago, various geological surveys in this country were established or reorganized, those entrusted with the work soon found that, if speedy and exact results were to be secured, and if substantial data were to be obtained upon which all other workers could also build, something else must be devised than the existing scheme of vaguely defined geological formations, having no comparable limits in different provinces and even diverse values in different parts of the same province. A natural, yet elastic foundation must be secured. Practical experience and the demands of the times quickly pointed out a suitable plan. So well has it served the purpose and so readily adaptable is it to the varying conditions met with on all sides, and the unforeseen exigencies constantly arising, that it has brought under its standard nearly every practical field geologist.

The method of designating geological formations by geographical names certainly does greatly increase the nomenclature, at times seemingly to a burdensome extent. This appears to be the only objection that has been yet urged against it that might call for notice. Yet, to all, except those who do not care to go beyond the ordinary text-book in geological work, even this seems hardly necessary, since it is offset by so many manifest advantages.

It may be truly said that no greater boon to the working geologist has been yet devised, than the plan of designating, geographically, geological units irrespective of exact position or age. Incorporated in the new plan are all the salient good features of the old method, while none of the objectional ones are retained. Since its adoption a vast mass of valuable information has been obtained that was previously unthought of, information that is in a shape to be always used, without the necessity of the user personally going all over the ground again; the other departments of geology have been greatly aided; and stratigraphical geology itself has made greater real progress in the short decade that has elapsed since the method with its new impetus came into general use than in all time previous. In the same short period more has been learned about the nature of sedimentation, the actual relations existing between rock formations, and the structure of the lithosphere than was possible before. In fact a rational physical basis for geological correlation and classification has been found.

The real meaning, then, of the multitude of new names that has recently made its appearance in the literature of stratigraphy, is the practical adoption of more refined methods of geological work, the provision of suitable means for the collection of more exact geological data, and the grasping of more advanced and rational conceptions regarding geological correlation and classification.

CHARLES R. KEYES.

THE WEATHERED ZONE (SANGAMON) BETWEEN THE IOWAN LOESS AND ILLINOIAN TILL SHEET.

PRELIMINARY STATEMENT.

Extent of Illinoian till sheet.—The Illinoian till sheet here discussed was formed by the Illinois glacial lobe in connection with the maximum extension of that lobe. It seems quite well established that a lobe on the east, which covered southeastern Indiana and southwestern Ohio and extended a short distance into Kentucky also had its culmination at the Illinonian stage of glaciation. Farther east the Wisconsin sheet in many places reaches the glacial boundary, but there are small tracts of drift older than the Wisconsin, lying outside its limits in eastern Ohio, northwestern and northeastern Pennsylvania, and northern New Jersey, which may prove to be of Illinoian age, though this is as yet not established. To the west of the Illinois glacial lobe there is a large area covering northern Missouri, southern Iowa, northeastern Kansas and eastern Nebraska, in which the upper sheet of till is older than the Illinoian, and is now referred to the Kansan stage of glaciation. The lobe which formed it is here referred to as the western lobe, for it has as yet received no more definite name. The Illinoian sheet has not been recognized farther west than the limits of the Illinois glacial lobe. It seems probable, however, that it may be found in the western region, and possibly it occurs as far south as northern Iowa.

The Illinois glacial lobe at its maximum extension to the southwest, crossed the Mississippi and encroached a few miles on Iowa, in the district between Clinton and Ft. Madison. But farther north and south it appears to have terminated east of the Mississippi, except, perhaps, for a few miles near St. Louis, Mo. The southern border of this lobe apparently reached to the glacial boundary from St. Louis eastward as indicated above. It is the southwestern border which claims our attention at this time, since the Illinois lobe there overrode to some extent the sheet of Kansan drift, formed by the western lobe which covered much of Iowa and portions of the neighboring states.

The southwestern limits of the Illinoian drift is usually marked by a definite marginal ridge or by chains of knolly and slightly ridged drift. Beginning at the south, in Jersey county, Ill., a few miles north of St. Louis, and tracing northward, the margin is found to follow the east side of the Illinois River in Jersey and Greene counties, and to carry only occasional knolls and low ridges. It crosses the Illinois in southeastern Pike county and takes a northwest course, coming to the Mississippi bluff near the line of Pike and Adams counties. It there enters a district which had been covered by the western lobe at the Kansan invasion. The Illinoian border takes a northward course along or near the east bluff of the Mississippi through Adams and Hancock counties. A definite ridge twenty to forty feet high is developed along much of the Illinoian margin in Pike and Adams counties, and as far north in Hancock county as a point opposite Keokuk, Iowa. For a few miles above Keokuk the Mississippi River apparently follows nearly the border of the Illinoian till sheet, and no definite ridges are found. At the bend of the Mississippi below Ft. Madison the Illinoian border crosses into Iowa. Its marginal ridge can be traced without difficulty from the vicinity of the Mississippi River bluff south of West Point, Iowa, northward through Lee, southeastern Henry, northwestern Des Moines and western Louisa counties to the Iowa River at Columbus Junction. Its course there changes to the northeast, and it can be traced diagonally across Muscatine county from its southwest to its northeast corner. It has been traced no farther to the northeast because of concealment by a heavy sheet of loess which borders the Iowan till in Scott county, Iowa. It is known to extend as far north as Scott county, for the Illinois till sheet has been observed in southern Scott county as far east as Davenport. The concealment by the Iowan loess is very great, not only in Scott county, Iowa, but also in Rock Island, Whiteside and Carroll counties, Ill. It becomes a difficult matter, therefore, to decide upon the position of the margin of the Illinoian drift in any of these counties. It is also not fully decided whether it reaches to the border of the driftless area in Jo Daviess and northwestern Carroll counties, Ill , and in southwestern Wisconsin. The balance of probabilities, however, seems to favor its extending to the driftless area.

The Illinoian till sheet overlaps a few miles the Kansan till sheet of the western lobe from the latitude of Hannibal, Mo., northward to the vicinity of the southern point of the driftless area. In this region of overlap a weathered zone is developed between the Illinoian and Kansan till sheets at the level of the outlying Kansan surface as indicated below.

Introduction of the name Illinoian.—The tracing of this southwestern border of the Illinois lobe was begun by the writer in the autumn of 1892, and carried as far north as Hancock county, Ill., that season. No opportunity to continue the study was afforded until the spring of 1894, when the mapping of the border was carried from Lee county, Iowa, northward to Scott county. The greater part of the data presented in this paper, and conclusive evidence of a long interval between the deposition of the till sheets now known as the Kansan and Illinoian, and also the evidence that the Illinoian is much older than the Iowan had been obtained as early as June 1894. The writer then began to use the name Illinoian in correspondence, but it seemed best to defer its introduction into literature until opportunity had been afforded other geologists to examine it. In August 1896 Professor T. C. Chamberlin and Dr. H. F. Bain were conducted by the writer to some of the exposures in southeastern Iowa which show the soil above and below the sheet formed by the Illinois lobe, and each recognized the need for a distinctive name for this drift sheet. The name was accordingly soon introduced into geological literature by Professor Chamberlin.[1]

Other interpretations.—At the ninth annual meeting of the Iowa

[1] See editorial JOUR. GEOL., October–November 1896, pp. 872–876.

Academy, held December 1894, Mr. F. M. Fultz read a paper[1] in which the interpretation was presented that the ice lobes alternated in the occupancy of the district south of the driftless area, and that the latest occupancy was by the western lobe. The extension of the eastern lobe into Iowa had been inferred by him through the discovery of a bowlder of red jasper conglomerate near Augusta, Iowa, which was apparently brought from north of Lake Huron. The evidence of an extension of the western lobe over the same district was found in eastward-bearing striæ along the brow of the Mississippi bluff at points farther east than the site of this bowlder. Mr. Fultz argued that if the striæ are not the product of the latest invasion they would not have been preserved in such an exposed situation. He also referred to some bowlder strewn terraces in the Mississippi valley at and above Keokuk as moraines, and correlated them with the striæ as the product of the last ice invasion. The following summer Mr. Fultz and the writer, while examining some rock outcrops in Burlington, found a striated surface in which the bearing is westward. This was evidently produced by the Illinois lobe, and as it is in a section about as exposed to obliteration by a subsequent invasion as those cited by Mr. Fultz in his paper it became necessary to readjust the views set forth in that paper. This was done at the tenth meeting of the Academy in December 1895, and the question of the relation of the two invasions was there left somewhat in doubt.[2] The bowldery terrace interpreted by Mr. Fultz to be a terminal moraine has been examined by Professor T. C. Chamberlin and Dr. H. F. Bain, as well as by myself, and to each of us it seems best explained as a residue of coarse material formed by a stream excavation along the Mississippi valley subsequent to the later ice invasion. The evidence that the Illinois lobe was last on this ground seems conclusively shown in the relation of its till sheet to that of the sheet formed by the western lobe. The latter can be traced under the Illinoian sheet as indicated below. In addition

[1] Proc. Iowa Acad. of Sciences, Vol. II, 1895, pp. 209–212.

[2] *Ibid.*, Vol. III, 1896, pp. 60–62.

to this evidence there is found an abandoned river channel in the district immediately west of the limits of the Illinoian drift which carried southward the drainage outside the Illinois ice lobe. The banks of this channel are well defined, and the channel evidently has not been filled by the drift of any subsequent invasion.

Extent of the Iowan loess.—By the term Iowan loess is meant that sheet of loess which connects at the north with the Iowan till sheet. A till sheet of Iowan age has been found in northern Illinois as well as in eastern Iowa and it probably covers the greater part of the northern half of Illinois. It is, however, covered by the Wisconsin till sheet from Bureau county, Illinois, east and south. How much of Indiana and Ohio was covered by the Iowan ice invasion has not been determined. The Iowan till certainly does not extend as far south as the Wisconsin in those states. The loess forms a heavy deposit along the border of the Mississippi and Illinois valleys, but is comparatively thin in the region east of the Illinois, its average thickness being scarcely ten feet. A silt tentatively correlated with the loess covers the Illinoian till sheet wherever exposed outside the Wisconsin from the Illinois River eastward to central Ohio. The Sangamon weathered zone between the loess and the Illinoian till sheet is found from central Ohio westward to southeastern Iowa, *i. e.*, to the limits of the Illinoian till sheet. The Iowan loess extends also over the Kansan till sheet of southern Iowa and adjacent portions of Missouri, Kansas and Nebraska, but this loess is separated from the underlying till by a much longer interval than that between the loess and the Illinoian till sheet, an interval comprising two interglacial stages and one glacial stage.

Application of Buchanan.—At the tenth annual meeting of the Iowa Academy Professor Samuel Calvin, after describing certain gravel deposits in northeastern Iowa, introduced the term Buchanan as a name for an interglacial stage following the Kansan,[1] and made the following statement concerning the origin and age of the deposits:

[1] Proc. Iowa Acad. of Sciences, Vol. III, 1896, pp. 56-60.

As to their origin the Buchanan gravels are made up of materials derived from the Kansan drift. As to age they must have been laid down in a body of water immediately behind the retreating edge of the Kansan ice.

Manifestly the deposition of the Buchanan gravels covers but a small part of the time between the Kansan retreat and the Iowan advance. Unless therefore the deposition and subsequent weathering both be included under this name it does not fill an interglacial stage. Were there no Illinoian glacial stage to break the continuity of interglacial conditions from the Kansan to the Iowan stage of glaciation it would not seem necessary to look for other terms. But in view of this glacial interruption there seems need for names which will stand for the weathered zones above and below the Illinoian till sheet. It is for this reason that the name Sangamon is here suggested for a weathered zone separating the Illinoian till from the overlying loess. In an accompanying paper the name Yarmouth is introduced for the weathered zone between the Illinoian and Kansan till sheets. The name Buchanan may still have the significance given it by Professor Calvin; and if weathering be included may perhaps be used to cover the time involved in the two interglacial stages with the intervening glacial stage.

THE SANGAMON WEATHERED ZONE.

Earliest recognition.—Apparently the first recognition of the occurrence of a definite soil horizon between the Iowan loess and the Illinoian till sheet is that reported by Professor A. H. Worthen, in the Geology of Illinois.[1] In his report on Sangamon county, Illinois, made in 1873, Professor Worthen called attention to a soil found at the base of the loess in Sangamon and neighboring counties. The soil apparently was first noted by Mr. Joseph Mitchell, in the excavation of wells in the northwest part of the county and in neighboring portions of Menard county. Mr. Mitchell furnished for publication in the Geology of Illinois the following section of the beds usually penetrated.

[1] Geol. of Illinois, Vol. V, 1873, pp. 306-319.

	Feet
Soil, - - - - - - - - -	1 to 2½
Yellow clay, - - - - - - - -	3
Whitish jointed clay with shells, - - -	5 to 8
Black muck with fragments of wood, - - -	3 to 8
Bluish colored bowlder clay, - - - -	8 to 10
Gray hardpan — very hard, - - - - - -	2
Soft blue clay without bowlders, - - -	20 to 40

Professor Worthen states that the bed overlying the black muck is undoubtedly loess, also that the black muck indicates conditions suitable for the growth of arboreal vegetation in the interval between the deposition of the bowlder clay and the overlying loess. The name Sangamon is taken from this locality where the soil was first reported.

General prevalence of a weathered zone at the base of the Iowan loess.—In the locality just mentioned there appears to be only a bed of muck to indicate the interval between the deposition of the bowlder clay and that of the overlying loess, for the clay immediately below the muck is described as of a blue color, a feature which suggests that there was not much oxidation and leaching, or else that there was subsequent deoxidization. The more common phase is a reddish brown till surface for which Dr. H. F. Bain has proposed the Italian name "ferretto,"[1] which may or may not be accompanied by a black soil. This reddish-brown surface appears to have been developed in all places where there was fairly good drainage. But in places where the drainage was imperfect a black muck of considerable depth accumulated and the reddened zone was imperfectly or not at all developed. In western Illinois the exposures of a black soil at the base of the loess are relatively few, but the reddened till surface is a common feature in every township. In much of the white clay district of southern Illinois and in portions of the Sangamon drainage basin a black soil is well developed. It is also well developed in southeastern Iowa. Where the black soil is best developed leaching is found to have extended in places only one to two feet into the underlying till but it often extends to a depth of

[1] See Proc. Iowa Acad. of Sciences, Vol. V, 1898 (in press).

six feet or more. Where it is absent the leaching generally extends to a depth of six feet below the base of the loess. The variations in depth of leaching appear to depend on the conditions for percolation of water, being greatest where percolation is most rapid.

Noteworthy exposures of Sangamon soil.— A few instances of the exposures of this soil are selected which will illustrate the variability in its character. The first section, at Ashland, Ill., is near the place where Professor Worthen reported its occurrence.

The following series of drift beds were penetrated by a coal shaft at Ashland, the identifications being made by the writer from samples of the material preserved at the engine house:

	Feet
Soil,	1½
Yellow loess, fossiliferous,	9
Blue loess,	2
Peat with black, sandy slush,	22
Bluish, gummy clay with few pebbles,	20
Yellow till,	30
Total drift,	84½

At the air shaft sand was found in the place of the blue gummy clay beneath the peaty slush. A similar thick bed of peat has been noted at several other points in that region, one of the most conspicuous being in a well at Virginia City made by Mr. Oldridge. The peat was entered at the base of the loess at about 15 feet and continued to a depth of 28 feet, beneath which a blue gummy clay was found. The drift at Virginia City has a depth of 187 feet, as shown by the coal shaft. This shaft is reported to have passed through a lower black soil between till sheets at 67 to 70 feet.

In the south part of the Sangamon basin, in the vicinity of Taylorville, Ill., the loess which has a thickness of 10 to 15 feet is underlaid by beds of sand and gravel, carrying thin peat beds in their midst as well as at the junction of the loess and the sand. At the Taylorville coal shaft the uppermost peat bed was found at 13 to 15 feet, and the lowest at 40 to 44 feet. Numerous exposures of this peaty material alternating with sand beds may be seen in ravines in that vicinity.

In October 1896, Professor Chamberlin and the writer examined together numerous exposures of the Sangamon soil in the portion of eastern Illinois south of the limits of the Wisconsin drift, chiefly in Cumberland, Coles, and Shelby counties. North of Greenup there are exposures where the subsoil beneath the Sangamon soil is traversed by branching rootlike tubes one to two inches in diameter, which were easily traced ten to twelve inches below the soil proper. These tubes are filled with the black soil which apparently settled into them upon the decay of tree roots. There seems to us little question that the Sangamon soil here supported a forest. The till below this soil in these counties shows leaching to a depth of several feet. It also presents weathered cracks and seams extending down a depth of 20 feet or more. Similar leaching and weathering below the Sangamon soil has been observed by the writer in several other counties in southeastern Illinois, and in Vigo, Clay, and Sullivan counties in southwestern Indiana, thus extending it to the southeast border of the Illinois lobe.

Returning to western Illinois, excellent exposures of black soil and leached subsoil are found along the Santa Fé railway in eastern Knox county. The soil may be seen distinctly at a distance of nearly one-fourth mile. It is of a deep black color, resembling the surface muck found in flat portions of the uplands. The till beneath it has been leached to a depth of about four feet. The loess has a thickness of 12 feet, and is slightly calcareous in the lower portion. The entire leaching of the till may confidently be referred to a date earlier than the loess deposition.

At Galva, Ill., a black soil at the base of the loess is well exposed in a clay pit at the brick yards east of the city. A large log was found imbedded in this soil, which here has a depth of two feet. The overlying loess is 15 feet in depth. A well at the brick yards penetrated 40 feet of till below the buried soil, of which the upper 30 feet has a yellow color and the remainder a blue-gray color.

In southwestern Carroll county, Illinois, there are extensive exposures of a soil at the base of the loess, made by the Chicago, Burlington and Northern Railway Company, the loess having been removed to make a fill across the valley of Johnson Creek. Probably a half acre of the buried soil is here exposed to view. It has a deep black color to a depth of 10 or 12 inches, beneath which it assumes a greenish yellow color, such as is presented by subsoils beneath poorly drained regions. This subsoil is leached as far down as exposed, a depth of three feet. This locality was visited last November by Professors Calvin, Udden, Bain, and myself, and each recognized the clear indications of a long interval prior to the loess deposition. It may be noted in this connection that Judge James Shaw mentioned a soil in Carroll county in his report on the Geology of Illinois, which apparently has the same horizon as the one just described. It was found at a depth of 15 feet and a deposit of wood two or three feet in thickness was associated with it.[1]

On the portion of the Illinoian sheet in southeastern Iowa many excellent exposures of the Sangamon soil are found. An exposure similar to that in Carroll county, Illinois, has been made at West Point, Iowa, where the Chicago, Ft. Madison and Des Moines Railway Company has excavated to obtain filling for its tracks. The loess has been removed over an area several rods square, leaving the buried soil at the base of the excavation. Although the exposure is on the crest of the ridge which marks the western limits of the Illinoian drift, the soil is of a deep black color and has a depth of several inches. This exposure was visited by Professor Chamberlin, Dr. Bain, and myself in August 1896, as were also several roadside exposures between West Point and Denmark, and between Denmark and Ft. Madison.

Exposures in other portions of southeastern Iowa are given in connection with the discussion of the Yarmouth weathered zone.

Valley excavation during the Sangamon interglacial stage.—The large streams in western Illinois and southeastern Iowa are

[1] Geology of Illinois, Vol. V, p. 80.

characterized by high-level terraces. The valleys of which these terraces are the bottoms have been formed in the Illinoian till sheet, and are covered by the Iowan loess. The excavation may, therefore, be referred to the Sangamon interglacial stage. They are broad and very shallow. On Skunk River, along the borders of Lee and Des Moines counties, Iowa, the terrace is only 30 to 40 feet below the level of the uplands, but the valley is nearly two miles in average breadth. The valley cut below the level of the terrace is more than 100 feet in depth, but is only one-half mile in average breadth. These features indicate that during the Sangamon interglacial stage the stream had a lower gradient than at subsequent stages. On the neighboring portion of the Mississippi the valley formed at the Sangamon stage was shallow, as on Skunk River, but was not much wider than the inner valley. The large volume of water flowing through the valley at the time when it constituted an outlet for the glacial Lake Agassiz and the glacial lake in the Superior basin is perhaps the cause for the relatively great erosion subsequent to the Sangamon interglacial stage.

In southern Illinois and southwestern Indiana the main streams usually flow in broad shallow valleys, in some cases several miles in width, which were apparently built up by the glacial and fluvio-glacial deposits of Illinoian age. It is seldom that sufficient deepening of streams has occurred to produce well-defined terraces; and it is not an easy matter to determine the amount of work accomplished during the Sangamon interglacial stage. On the borders of these lowlands the Iowan loess rises above the level of the modern streams and at such places occasional exposures were found in which the junction of Iowan loess and the Illinoian till is marked by a thin bed of material more pebbly than the typical till; a feature which is thought to indicate moderate stream action prior to the deposition of the loess. A similar feature has been noted on the borders of many of the small valleys in western Illinois and southeastern Iowa.

FRANK LEVERETT.

STUDIES IN THE DRIFTLESS REGION OF WISCONSIN II.[1]

Since my article which appeared in the November-December number of the Journal of Geology was written, much additional evidence has accumulated, largely along new and supplementary lines. There have, however, been some additions along the lines there developed, which I beg to notice in an extended footnote.[2]

[1] On page 834 of my last article a change in the paragraphing somewhat obscured the course of the reasoning. The objections to torrential action were grouped under three heads: *a*, transverse ridges, beginning at the tenth line from the top; *b*, the lateral ridges; *c*, the size of the material.

The first head was improperly made to begin at the twenty-third line from the top, where there is only a reference to the ridge, *b*, Fig. 1. I think that I was myself partly the occasion of the mistake, since the *b* stood alone, Fig. 1 having been omitted. The third head should have been worded more in harmony with the others and more indicative of its own character.

[2] Regarding the ridge *d* (Fig. 1 of last article) I stated that it seems to belong structurally to both valleys. But the heavy masses of ferruginous sandstone which form so conspicuous a component of the ridge appear to be peculiar to the east valley. The knob *d* (Fig. 1) is composed of it. It also occurs on the north rim at *c* (Fig. 7). Although much harder than the sandstone in the same horizon on either side, it is not as prominent in the topography as we should have expected, owing probably to the fact that it has pronounced joint structure and the separate masses are rather easily dislodged. The supposed bowlder bed on the west side of the west valley (shown in gully) is of small material, undoubtedly a water deposit, leaving the ridge *b* (Fig. 1) as the terminal deposit for that valley.

An interesting feature has developed in connection with the ridge shown in Sec. 4, Fig. 2 of last article, occurring in the third valley described (position shown at *c*, Fig. 4). A well dug just in front of the line of the section struck at once into a clay resembling the loess and entirely free from stones. It continued in this for its entire depth, about twenty feet.

The terminal arrangements of the material in the last valley described (partly shown in Sec. 6, Fig. 2) displays a certain feature which claims further notice; an independence of the minor features of the topography, shown in the direction of movement and the disposition of the beds. In the accompanying figure I have represented by contour lines the original rock surface and by dots the contour of the lower end of the beds. The axis of the old valley runs very close under the eastern hill, while on the west a broad shelf rises gradually toward the nearest bluff.

Distribution of transported material on the higher slopes.—Most of the deposits previously described fall between the horizon of the present river-level and that of the highest terrace, so that although there seems to be excellent reason on other grounds

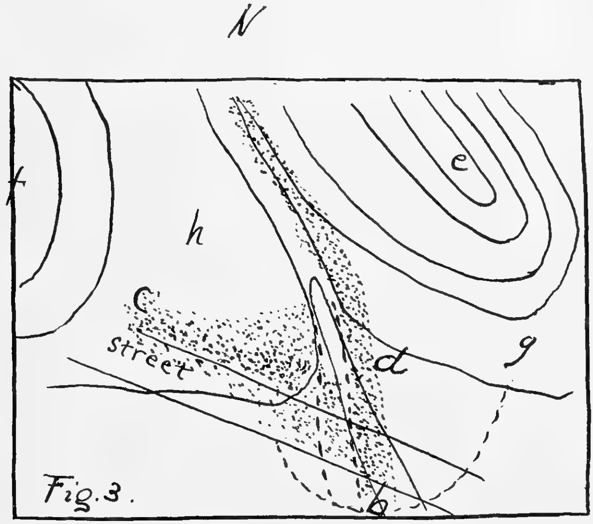


FIG. 3. Scale 300′ to an inch. Adapted from the village plat, which I used as the foundation.[1]

f. End of a short spur or projecting angle of one of the higher bluffs.

e. End of a long spur forming the northeast valley rim.

g, *h*. Rock shelves sloping gently from their adjacent hills.

ab. The bowlder ridge, the south end of which lies over the old rock valley, shown in entire lines, while the present drainage indicated by dotted lines runs further west just inside of the ridge. It has both an outward and an inward slope plainly apparent in spite of the loess, which, however, as the street cutting shows, greatly exaggerates its apparent breadth and diminishes its apparent height. The bowlder bed doubtless covers all of the shelf *h*, but being heavily covered with loess I have only indicated that part which is uncovered. On its south front it declines from a thickness of about twelve feet or fifteen feet to nothing in the width of a street.

The asymmetry of the deposits, *i. e.*, their presence on one side of a valley, and apparent absence on the other has been something of a difficulty in working out the

[1] These maps have necessarily been constructed without the aid of special measurements. But while they must needs lack the exactness which such a method would have given, they have been carefully constructed from fairly correct data, and after thorough study of the topography, and are essentially correct. The valley bottoms, however, offer especial difficulties, since the series of deposits of which the loess is the top, has been eroded so as to form a most intricate system of ravines of which only the principal ones could be represented.

for disputing the competency of running water, landslides or creep to give rise to such deposits, it cannot be denied that they lie within the horizon where such agents are operative. It is, therefore, very desirable to trace the deposits into higher levels. But the middle portions in all the valleys are so deeply covered by the loess—which has a strong tendency to fill up depressions and obliterate minor irregularities of surface—that nothing can be seen save in the rare cases in which gullies are deep enough to slightly expose the structure, and even these, although affording valuable evidence as to the sequence of the deposits, etc., give no decisive indication as to their character.

On the outlying secondary hills the loess is not so thick, and a systematic study of these has given unexpectedly interesting results. The accumulations there, unlike those of lower levels in which all the different local formations are represented, are composed almost exclusively of limestone from the tops of the

glacial hypothesis. But as shown above, while on one side the deposit may rest on a shelf, on the other it may lie in the axis of a valley, where if circumstances are favorable it may be covered by late deposits. This asymmetry is, however, quite as serious an objection to torrential action or to the flow of semiliquid material, neither of which could form deposits at a notably higher level on one side of a valley than on the other. At *c* the bowlder bed rises into a sharp ridge three or four feet high as shown in Sec 6, Fig. 2 (previous article). From *c* to *d* there is a nearly uniform eastward slope, broken only by the present drainage channel. Had there been nothing in the configuration of the ridge to confine the drainage it must have left the bowlder bed near *d*, to enter the lower level extending southeastward from thence. The dotted half circle drawn through points of approximately equal elevation on either side of the old drainage channel will show how widely the bowlder deposit departs from the normal plane of a water borne deposit.

There is an implied suggestion in Professor Chamberlin's note prefacing my first article, which requires more specific notice than I have yet given it. It is whether these deposits might not have resulted from landslides or from the lavalike flow of saturated earth during thaws, or the more gradual creep due to repeated thawing and freezing. Perhaps the best answer will be to state the conditions presented by a single case. The deposit shown in Sec. 3 (Fig. 2) of last article lies on a rock shelf and reaches to about forty feet above low water of the Mississippi, a height which is not reached in the valley for several hundred feet back. A 2° slope would not intersect the bottom of the valley at a distance much, if any, short of 1500 feet. To reach its present position from any possible source the material would have had to travel about 3000 feet and make a sharp bend in its course. Its probable source was one of the bluffs shown in Figs. 4 and 5, present article. Limestone is abundant in the deposit, and some of the fragments quite large.

higher bluffs. To this is added a comparatively small percentage of material from the transition beds at the base of the limestone.

Circs. — Short, direct valleys, with broad heads and narrow outlets, are finely shown in this vicinity. The deposits found in

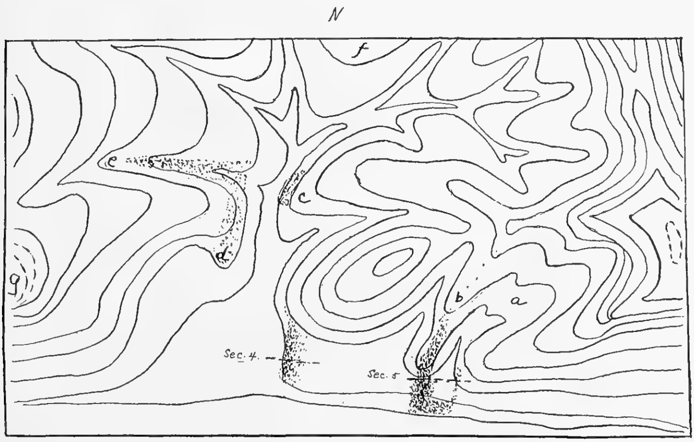


FIG. 4. Contour sketch map in which the center is occupied by the lower end of a large valley — the third in the series described. At the extreme right is a bluff, the highest and most massive in the group. Descending from this is the small valley or circ, *a*, the fourth described. The positions of Sects. 4 and 5 (Fig. 2) of the previous article are indicated. The bowlder deposits shown in Sec. 5 continue along up the crest of the ridge *b*, as shown by dots. I have endeavored by the greater or less concentration of the dots to indicate the relative abundance of the bowlder deposits. Sec. 4 (Fig. 2) was obtained at the point *c*. The peculiar point *d* appears to be largely or wholly composed of similar deposits. In the ravine, *e*, extensive washouts reveal very thick bowlder deposits. Doubtless similar deposits occur in the other ravines within the secondary hills, but the conditions are not favorable for observation. The lower end of the bowlder covered spur shown in Fig. 4 is seen at *f*. West of the middle of the valley, no hills reach the limestone horizon, save that at *g*. Scale 1000′ to an inch. Contour lines at intervals of 50′.

In this and the following maps I have indicated the base of the limestone horizon by heavier contour lines.

connection with them show several marked variations in detail from those found in the larger valleys, while they have a close resemblance among themselves. They all front on the Mississippi and are the result of the comparatively rapid erosion which its presence induces. The secondary hills which separate neighboring circs are very wide at the outer margins, but narrow to ridges of only a few feet in width at the points where they join the primary bluffs. In some cases these connecting ridges have been so

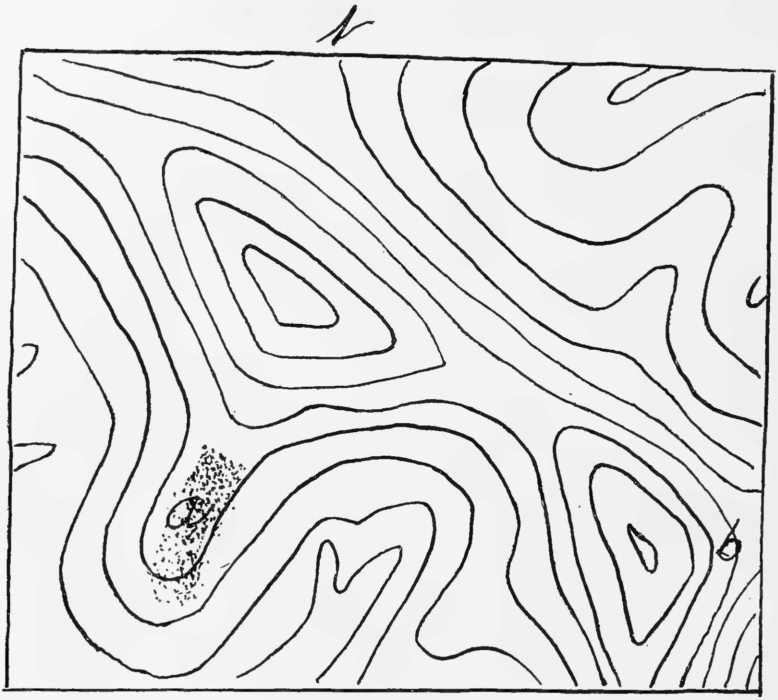


FIG. 5.—Sketch map of a portion of the same valley as shown in Fig. 4, joining that on the north—(east end). It shows a spur extending out from one of the angles of a limestone-covered bluff and having its top covered with limestone débris. It appears to extend downward somewhat on the east side, but, on account of the increasing thickness of the loess, it cannot be told how far. At *b* a spur of very similar height and form holds almost identical relations to its primary bluff, but it is entirely destitute of limestone débris. It is evident, therefore, that one has been subject to the action of some agent which did not effect the other. Scale 500′ to an inch. Contour lines at intervals of 50′.

worn away as to form a considerable sag. For convenience, I will speak of these secondary hills between circs as buttresses.

For the purpose of illustration I have selected one of the finest of these, which is shown in contour lines in the accompanying

panying sketch map, Fig. 6, together with portions of the circs adjoining on either side. A portion of the main bluff, with its limestone cap, is shown in the upper right-hand corner (in order

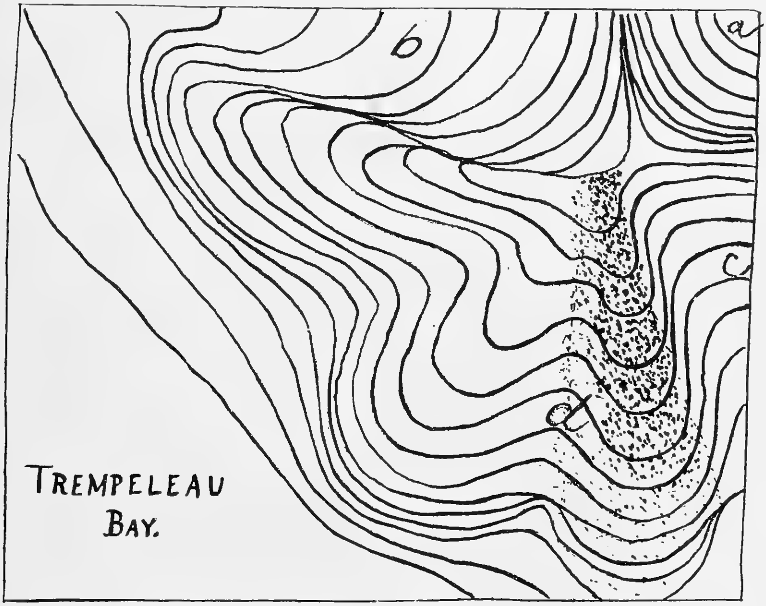


FIG. 6. Contour sketch map of a single buttress with a portion of its primary bluff, *a*, to illustrate the distribution of the limestone débris as shown in connection with the circs. Parts of two circs are shown, *b* and *c*.

The dotted portion shows where the limestone débris occurs. I have endeavored to show its relative abundance by the concentration of the dots. It should be observed, however, that while on the side furthest from the circ it is really represented by only scattered fragments, in the thickest part next the circ it is piled up to a thickness apparently of several feet. The side of the buttress toward the circ *c* is steep but not precipitous, but that toward *b* is a vertical escarpment several hundred feet long, and twenty to fifty feet high.

Scale 400′ to an inch. Contour lines at intervals of 25′.

to be more easily distinguished by the eye, the base of the limestone is represented by heavier contour lines). The dotted area on the east side of the buttress shows the portion covered by transported limestone. It is most abundant immediately adjoining a circ, diminishing as we recede from that, but not entirely ceasing until we have passed the bottom of the nearest ravine (*d*, Fig. 6). When it occurs on both sides of a buttress, and there is but a single intermediate ravine, it extends in some degree over all parts. The maximum thickness of these accumu lations is nowhere shown in section. Such indications as I have noted lead me to the belief that it will probably not exceed six feet or seven feet, thinning off until it is represented by scattered bowlders only. There is often an appearance as though the material had been thrown into subordinate ridges of low relief. They are too faint, however, to be relied upon as evidence, unless their reality can be confirmed by sections. The fragments range from massive or tabular forms several feet across down through all grades, and they lie as close together as the fragments in a macadamized road. The slopes from the circs to the bounding buttresses are nearly always steep (35° to 40°). That overlooking the circ *b* (Fig. 6) is vertical for heights varying from twenty to fifty feet. The small valley shown at *a*, Fig. 4 has somewhat the character of a circ. The sharp ridge which forms its western rim, or buttress, has a train of limestone débris for the greater part of its length, sometimes rather straggling, but quite abundant on its knoblike outer end, and the terminal slope, at the bottom of which it connects with the ridge shown in Sec. 5, Fig. 2 (previous article).

The larger valleys.—Of the occurrences in the larger valleys two examples are here sketched. The first, Fig. 5, is found in the largest of the valleys (the third described in previous article). The highest portion of its rim lies toward the northeast (compare Fig. 4), and a portion of this, a peak of triangular form, is shown in the figure. The northwest-southwest portion is a part of the valley rim, while the spur, *a*, projects into the valley. The top of this spur is thickly covered with limestone débris, save the inner end, and the slope of the main bluff up to the base of the limestone, where it is lacking. Whether the deposit on the spur is continued eastward and southward into the valley cannot be told on account of the loess. The second example, shown in Fig. 7, occurs in the easternmost of the two confluent valleys first described, in which the highest portion of the rim is toward the northwest, and consists of a high and rather long bluff, somewhat crescentic in form. The north rim of the valley consists of a much lower ridge, nowhere reaching

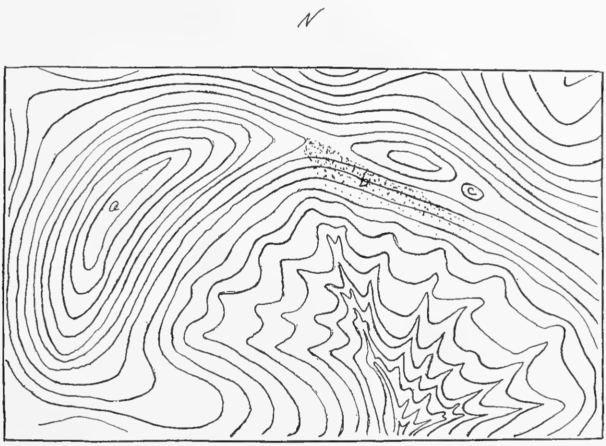


FIG. 7. Contour sketch map of the easternmost of the two confluent valleys first described in the last article. (The lower part is shown in Fig. 1.) The enclosing rim of the valley reaches the limestone horizon at only two points. One of these is the long bluff, *a*. The other would fall a couple of inches outside of the lower right-hand corner and is the same as the one shown at *g*, Fig. 4. At *b* occurs the train of limestone débris. Its downward extension is concealed by loess. *c*, knob of hard, ferruginous sandstone.

Scale 800′ to an inch. Contour lines at intervals of 25′.

to the horizon of the limestone. In proceeding eastward from the base of the limestone at the northeast end of the high bluff, limestone débris is lacking for some three or four hundred feet. It then appears suddenly on the top of the ridge, extending to an unascertained distance downward on the inside. A little further eastward the upper edge of the débris begins to fall a little short of the top of the ridge (on the inner side), and from that point it continues to decline at a nearly uniform rate, making an angle of about 4° or 5° with the horizon. The limestone is in sufficient abundance to wholly cover the ground up to almost the extreme limit of its occurrence, when within the space of a foot or two it fails entirely. The figure does not exaggerate the nearly straight course followed by the upper margin of the deposit (to avoid misapprehension I may say that throughout the article, in speaking of limestone, only that derived from the Lower Magnesian horizon forming the caps of the higher bluffs is regarded, the limestone found at lower levels and belonging to the Potsdam series being carefully excluded).

I would call attention to the fact that all the examples given lie over against projecting angles of the primary bluffs. To reach the position occupied, material must have moved in defiance of the law which requires that it shall travel along the shortest available course from a higher to a lower level. We are obliged to account not for a few sporadic cases of such transportation merely, but for such an abundance as really amounts to a concentration. I therefore feel justified in saying that under existing conditions it is quite impossible that the material should have reached its present lodgment by rolling from the higher bluffs. In the case of the deposits on the buttresses, I have speculated as to the possibility of their having been earlier accumulations antedating the formation of the circs. But the hypothesis fails to explain all the facts even in these cases, and is of no assistance whatever in cases like those illustrated in Fig. 5 or Fig. 7.

The only tenable hypothesis remaining, as it seems to me, is that the valleys were filled with wind-drifted snow, which was piled up around the higher bluffs, so that only their limestone tops rose above. In such a case the limestone débris which reached the upper edge of the drifts would sooner or later work downward to a lodgment wherever the slope and other conditions were favorable. This involves the further assumption that the snow had been compacted to practically the consistency of glacier ice. So far as I have been able to bring it to a test, this hypothesis explains the various peculiarities remarkably well. All the localities showing limestone débris thus far discovered, are in places where, under the hypothesis, they would have been most likely to occur. Compare Fig. 5 and explanatory notes. The minor features of distribution also harmonize well with it; for example, in Fig. 6, limestone is wanting on the north side of the buttress. But this side is remarkably high and the height is maintained for a long distance, and the upper surface of a drift having the average slope would have fallen much below the top of the perpendicular escarpment. Conversely there are other buttresses so small that a drift having the average slope would have buried them completely, and these also are destitute of the limestone.

It is evident that on this hypothesis the limestone accumulations furnish data from which we may calculate approximately some of the dimensions of the drifts. In some of the circs the slope may have been as high as 20° in places, but the average appears to have been nearer 15°. In the valleys it was much less, apparently ranging from 10° or 12° down to 4° or 5°. The greatest vertical thickness appears to have ranged between 200 and 250 feet in the valleys and between 80 and 120 feet in the circs

The hypothesis does not necessarily imply that the big drifts developed glacial motion, since the transit across their upper surfaces might have taken place though the drifts were themselves stationary. But if we may accept the existence of large bodies of snow in the valleys, as probable, the indices of glaciation shown in the lower portions of the same valleys gain greatly in importance.

The facts above given regarding the distribution of limestone on the bounding buttresses of circs, seems to render it desirable that some notice should be taken of their low level deposits. Unlike those connected with the larger valleys, these are almost wholly external, and have the form of alluvial cones. As seen in section, they display the concentric structure lines indicating the successive stages of their upbuilding. These are more pronounced on either side of the center where also the material is usually fine.

Along the center, or axis, bedding planes are often faint, or lacking, and much heavy material is included. As might be expected, the coarse material is a fairly representative assemblage from the different horizons.

So far there is nothing to suggest glacial action. But two bowlders seen in the railroad cutting are noteworthy on account of their character, and certainly suggest some such agent. They are tabular forms six or seven feet across, and two to three feet thick, derived from the thin-bedded, impure limestones of the Potsdam series and are extremely fragile. One, indeed, is divided near the middle by what has every appearance of being an old joint about half an inch wide, and the sides still parallel. Their nearest point of origin was several hundred feet distant. How such masses could have traveled even a short distance without falling to pieces, it is hard to see, unless they were firmly embedded in some matrix.

From a variety of circumstancs, I have the impression that the circs have been well cleaned of rocky débris, and that such material is now accumulating at their upper ends. The indications are strong that little save the finer débris now passes out. For the present, however, I should not care to lay much stress on these impressions.

While these deposits must be regarded as essentially nonglacial, there does not appear to be anything inconsistent with the assumption that occasionally during periods of exceptional activity, glaciers may have advanced on to them for short periods.

The field is very far from having been exhaustively worked, and until evidence is more nearly complete I prefer to reserve final expression of opinion.

G. H. SQUIER.

FUCOIDS OR COPROLITES.

THE middle part of the Devonian section seen along the Mississippi River between Hampton in Illinois and Muscatine in Iowa consists of a shaly limestone, which is quite rich in fossils.[1] From this horizon I have for some time collected certain structures, which have a close resemblance to the fossils described by James Hall under the name *Spirophyton*,[2] and which occur in the rocks of the Hamilton period in New York. The fossils found here consist of flat cakes of calcareous material, from one to six millimeters in thickness and from five to thirty centimeters in width, intercalated among the layers of the rock, mostly lying parallel with these, and presenting an endless variety of forms (Figs. 1–8). The flat surfaces are bent in a succession of wave-like, crescentic, low and wide ridges, which become confluent and indistinct near the margin. Generally the widest ridges have a corresponding depression on the opposite side of the cake.

Much of Hall's description of *Spirophyton* is perfectly applicable to these fossils. Their substance is often "scarcely separable from the stony matrix," especially when the containing rock is unweathered. The wave-like ridges are "frequently not distinctly limited on the outer margin," which then appears to be continuous with a lamina in the rock (Fig. 8). In one instance there is a shallow groove following the edge of the cake on either side (Fig. 1) and resembling that seen in Hall's figure of *Spirophyton typum*.[3] The substance of the cake contains fragments of "small shells or fragments of shells." One of these is

[1] The part of the section to which is here referred is No. 4 in my paper, A Brief Description of the Section of Devonian Rocks, etc., published in the Journal of the Cin. Soc. of Nat. Hist., Vol. XIX, No. 3, pp. 93–95.

[2] Observations upon some Spiral-Growing Fucoidal Remains, etc., 16th Report on the State Cabinet of Nat. Hist., JAMES HALL, 1861–2, 76–83.

[3] HALL, loc. cit., Pl. II, Fig. 2.

apparently a minute pteropod. I have, however, been unable to find any spiral or helical forms like that of *Spirophyton typum.* The nearest approach to it is a twisting of that end of the cake toward which the concave sides of the ridges are directed (Fig 7).

There are several circumstances which point to a mechanical origin of these structures. The material of which they consist is a compact calcareous mass apparently identical to that of the surrounding rock. It is difficult to explain how this could have been introduced in such quantity and in such condition into the interior of a soft pulpy seaweed, and still have permitted the plant to leave a mold of both of its surfaces in the accumulating sediments. Another circumstance of similar significance is the indistinctness of the margins of some of the specimens. In their shapes, moreover, there is an indefinable lack of that uniformity of design which we are accustomed to find in organic forms. Unless certain ones are selected and others left out, classification on this basis seems impracticable. From Hall's description of the spiral-growing fucoids in the Devonian rocks in New York, it is evident that these also are variable in form, for he states that "the larger fronds not unfrequently present irregularities and distortions, both from unequal growth and from accident, evidently having been very flexible and easily disturbed," and he refers to some of the specimens as being "detached portions which have been distorted by pressure after their separation."

EXPLANATION OF PLATE VII.

FIG. 1. Dimensions: length, 19^{cm}; breadth 5.3^{cm}; average thickness, 2.5^{mm}.

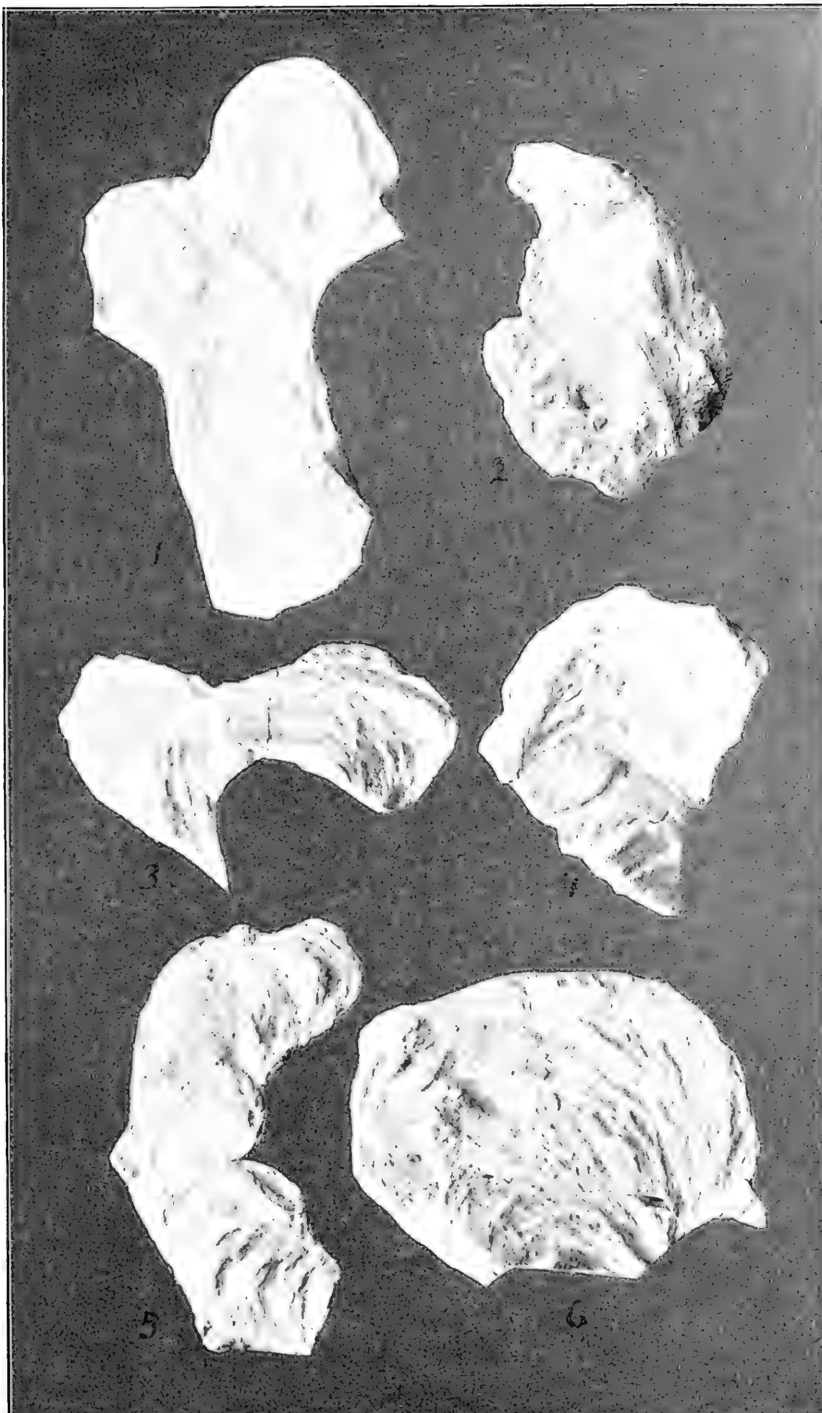
FIG. 2. Dimensions: length, 12.5^{cm}; breadth 8^{cm} at the widest point; average thickness, 2^{mm}.

FIG. 3. Dimensions: greatest diameter, 13^{cm}; average thickness, 4^{mm}. Evidently fragmentary.

FIG. 4. Dimensions: length, 12^{cm}; greatest breadth, 10.5^{cm}; thickness from 6^{mm} to 2^{mm}.

FIG. 5. Dimensions: length, 16^{cm}; average breadth, 5^{cm}; average thickness, 4.5^{mm}.

FIG. 6. Dimensions: greatest diameter, 14^{cm}; average thickness, 4.5^{mm}. Fragmentary.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The general appearance of the western specimens is such as to suggest that they have been formed from flowing mud. In some instances the crescentic ridges overlap, as if the flow had run over on itself. Near the edges of the specimens planes of divisions are sometimes seen, which readily might be accounted for as planes of differential motion in moving mud, but which seem difficult to explain if the specimens be regarded as imprints or casts of sea-weeds.

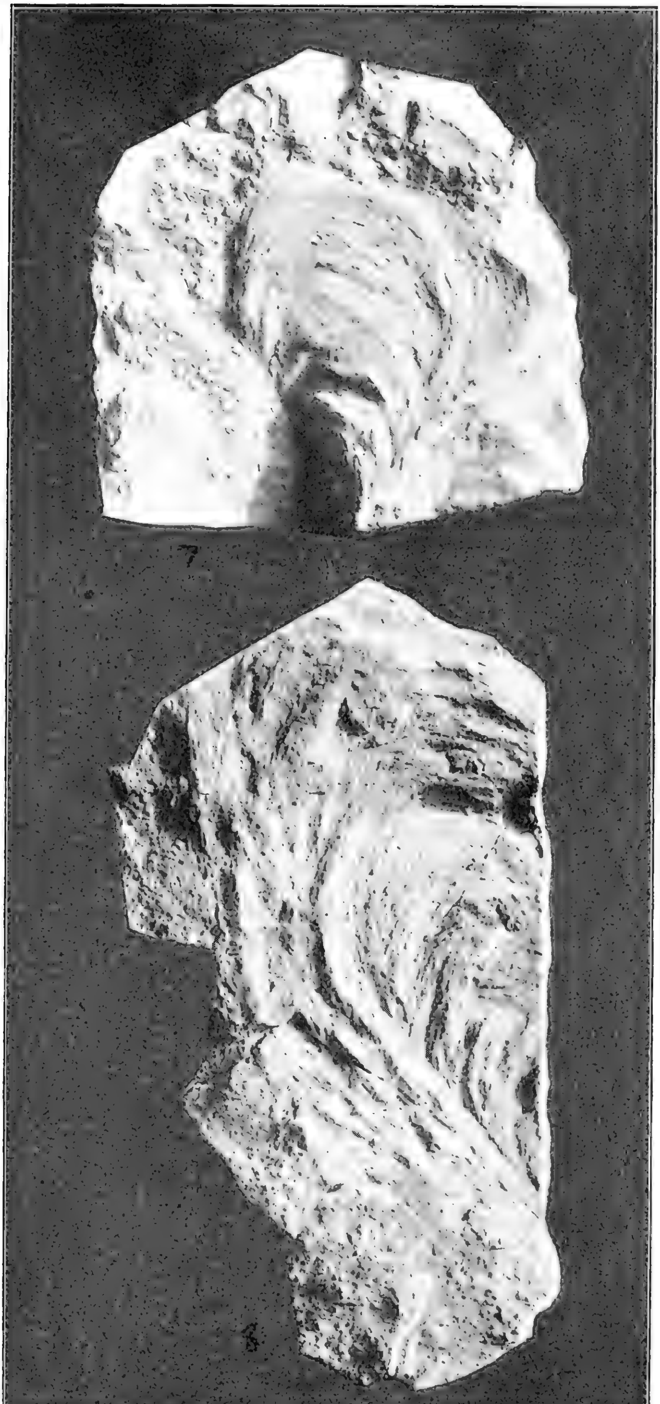
But the resemblance between these western specimens and *Spirophyton* is in general so perfect that there can hardly be any doubt that both have the same origin, and it is evident that the regular spiral frond of the latter, however rarely found, cannot have been produced except by the intervention of some organic agency. The quiet sea-bottom indicated by the nature of the sediments containing the fossils also preclude the possibility of the occurrence of mud-flow in the ordinary way under the conditions of deposition of the containing rock.

It seems, however, that cakes like these might be formed in just such situations from the voided contents of mud-eating animals, such as sea-cucumbers. These are known to burrow in the mud, far out in the sea, and to extract their food from such fragments of organic substance as they find in the ooze, mud, and sand with which they fill themselves, and which is afterward expelled by contractions of the visceral muscles. This may, no doubt, take place down in the mud as well as on the surface of the sea-bottom. If we suppose that the cakes have been formed in such a way, it is easy to account for their diversity of form—even when this takes on the complex twist of a spiral—and there will be no difficulty in explaining how it came about that they are molded from the same material as the surrounding matrix. A loose mud slowly forced out from a receding tube

EXPLANATION OF PLATE VIII.

FIG. 7. A specimen in the matrix. Length, 12^{cm}; breadth, 10^{cm}; thickness, 2^{mm}.

FIG. 8. Fragment of a large specimen cut by a joint in the rock obliquely, and confluent at the edge with a layer in the rock. Greatest length, 21.5^{cm}; breadth, 14^{cm}; average thickness, 4.5^{mm}.



can be made to settle in heaps which will have a noticeable resemblance to these peculiar fossils. This new interpretation of an obscure class of objects is given merely as an aid in their study. Though the holothurians are referred to as the animals most likely to produce coprolites of this kind, it is believed that any other mud-eating species of burrowing habits may just as well have done the work—soft animals, perhaps, that were sufficiently protected by their concealment in the ocean mud to render unnecessary any hard parts, which might have left less uncertain traces of their existence.

J. A. Udden.

Rock Island, Ill.

ZIRKELITE—A QUESTION OF PRIORITY.

In the *Mineralogical Magazine*, Vol. XI, pp. 86–88 (read June 18, 1895) is described a new mineral containing zirconium, titanium, lime, iron, etc., under the name of Zirkelite. This paper was prepared by my friend, Dr. E. Hussak, and by Mr. C. T. Prior. Later Mr. Prior (*loc. cit.* pp. 180–183, read Nov. 17, 1896) published an analysis of the same mineral.

I wish to protest against the use of the name Zirkelite for this mineral on the ground of the prior use of it to designate a commonly occurring rock belonging to the basaltic family.

When two subjects are so intimately connected as mineralogy and petrography it does not seem to be for the interest of science that names should be duplicated in them. So true is this that I abandoned the name Rosenbuschite, which I had given to a class of rocks in honor of Professor Rosenbusch, because only a few weeks previously it had been employed to designate a new mineral.

The term Zirkelite was used by me in 1887, or seven years before it was taken by Messrs. Hussak and Prior. (See Preliminary Description of the Peridotites, Gabbros, Diabases, and Andesites of Minnesota, *Bulletin No. 2*, Geological Survey of Minnesota, 1887, pp. 30–32.) It was used to designate the commonly occurring altered conditions of basaltic glassy lavas which are often called diabase glass, etc. Zirkelite occurs forming the entire mass of thin dikes, and the exterior parts of many dikes of diabase and melaphyre, as well as the surface of old lava flows like the melaphyres and diabases of Lake Superior, Newfoundland, and elsewhere. Zirkelite holds the same relation to tachylite that diabase and melaphyre do to basalt, *i. e.*, an older and altered type.* The macroscopic and microscopic characters of this rock were given in the locality cited above.

*

The term Zirkelite was again used in the same way in my *Report of the Geological Survey of Michigan* for 1891–2 (1893, pp. 90, 97, 138, etc.).

It was also published in my classification of rocks given in the *Catalogue of the Michigan College of Mines* (Michigan Mining School), 1891–2, p. 104; 1892–1894, Table XI; 1894–1896, Table XI.

Further the term Zirkelite is defined in accordance with my usage in Lewinson-Lessing's *Petrographisches Lexikon*, 1893, p. 252); and accounts of it are given in the *Neues Jahrbuch für Mineralogie*, 1893, II, p. 292, and in Kemp's *Handbook of Rocks*, 1896, p. 170.

M. E. Wadsworth.

Michigan College of Mines, Houghton, Mich.,
December 17, 1897.

[The prior use of the name *Zirkelite* is certainly established, but it is a question how far a petrographer is justified in stigmatizing the name of a fellow worker by attaching it to an indefinitely decomposed and ill-defined rock.—J. P. I.]

EDITORIAL.

Editors Journal of Geology:

I WOULD like to call attention to the constant misuse of a foreign word much used by glacial geologists. The word *aas* in the Danish, *ås* in Swedish, which in Norway is used for a rounded hill, and in Sweden and Finland especially for those long gravel ridges which are clearly of glacial origin, has its plural *åsar*. The word is pronounced like the *oas* of *boast*, and really the best way to transliterate it into English would be to spell it *oas* rather than *os*, as the long sound would then be more certainly given it. The plural would then be *osar* or *oasar*, which is, perhaps, preferable to *oases* for obvious reasons.

Therefore the writers who speak about "*an osar*," and mention "*the osars*," are producing the same kind of horrible hybrids that foreigners would who should speak of "*an oxen*" or "*I saw three mices*," mistakes of a kind which, in writing, are unnecessary.

L. V. PIRSSON.

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ANY protest that will help to a better use of terms in science or elsewhere is to be welcomed as a contribution toward the relief of one of the most grievous burdens of the intellectual world. The incompetencies and inadaptabilities of our vehicle of thought, to say nothing of its absurdities, are already most serious obstacles to intellectual progress, and they are daily growing in intensity and threaten to become altogether unendurable in the near future. In former times, when the substance of thought was limited, the intellectual gymnastics involved in mastering the idiosyncrasies of language were not without their compensations. But the time has come when even the essence of the most imperative thought has grown to such magnitude that any labor wasted upon the trammelings of verbiage falls into the category of the reprehensible. It would be an interesting investigation which should show how great an amount of ignorance of vital truths is justly chargeable to the time consumed in gaining a questionable mastery of the needless, not to say the positively pernicious, factors of a language whose evolution is a century behind the times. It would be an instructive investigation in criminology which should ascertain how much of suffering, death, and other disasters arise from crowding aside instruction in vital matters to make room for the dull grind upon the senseless conventionalities of a delinquent language.

To the already deplorable state of things chargeable to linguists, teachers, and the common public, the devotees of science are adding their special inflictions, and if present practices continue there will apparently be no remedy in the future but open rebellion. It is said that the number of organic species and varieties has grown already into the neighborhood of one million, and each of these is burdened with a binomial, if not a trinomial, designation consisting usually of an artificial breccia of Greek, Latin, local, personal, and other verbal fragments, rudely stuck together and finished off at the end in Latin fashion. They are "neither fish nor flesh, nor good red herring."

Our mineralogical terminology which endeavors to impose on all futurity unmouthable distortions of the names of insignificant streams or mountains or villages or collectors or scientific friends unworthily rivals the biological monstrosities. And when we come to compound these into the names of rocks, in pursuance of a most natural and laudable system of nomenclature, their uncouthness is more than doubly emphasized, and becomes almost prohibitory. If geologists in their own field are not coequal sinners, it is, perhaps, only due to a less urgent need for terms. When we contemplate that to which this inconsiderate practice will inevitably lead as the number of varieties and species and distinctions increase with the progress of research, the seriousness of the evil becomes intensified. When we compute the loss to the acquisition of the essential elements of science which must ensue if this system is perpetuated through the five to ten million years which the solar prophets assign as the possible future of the habitable earth the magnitude of the affliction grows to prodigious dimensions. It may be confidently predicted, however, that there will be a revolt in the not distant future if a rational movement toward reform is not soon inaugurated. In the meantime every little reform has an importance, not only in its own merit, but also in its moral effects as a step towards general reform.

Back of the special criticism of Professor Pirsson there is a general question which invites attention in connection with his protest: What considerations shall guide us in the endeavor to secure better practice? The word *ås*, *åsar*, was anglicized to osar, osars, a half century ago, and may be found current in the writings of Murchison, Desor, the elder Hitchcock, and others. Practice has been divided ever since between the alternative evils of introducing into the English language a word of irregular variation and uncertain pronunciation (to English people) with its consequent infelicities, or of ruthlessly modifying the Swedish word to suit English practice, with the barbarisms which Professor Pirsson points out. There is, however, a *tertium quid*, to which Americans are quite generally turning. It is the avoidance of both these alternatives and the adoption of the term *esker* instead, which in form and phonic nature is more acceptable. Whatever may be the method of formation of the plural of the ultimately perfected world language, it is quite certain that it will not follow the Swedish analogy *ås*, *åsar*, because this is not inherently meritorious. Hence we do the English language a poor service and put obstacles in the way of the ultimate common language by introducing a form not in itself worthy to endure. It may be urged as an objection to the term esker that *ås* had currency at an earlier date. If we are to give the law of priority its widest application, and bow unhesitatingly before it, the objection holds good. The writer has himself previously yielded to it. But on fuller consideration he withdraws from this position and favors the use of the inherently preferable term esker. While due regard should doubtless be paid to the law of priority, it seems obvious upon mature consideration that all future generations should not be made to suffer unduly for the infelicities of the first usage often carelessly inaugurated. The improvement of the language should have first thought, and be given determinative weight in all permissible cases. The evolution of a common vehicle of thought for all the world will grow more imperative as intercommunication and common sympathy become more universal, and the rapid increase of vital knowledge and the more strenuous demands of a higher civilization will require that this vehicle shall be not only surpassingly rich in its resources, but economical in its modes of operation. Intellectual wastefulness is as reprehensible as material wastefulness, and our vehicle of thought should be as assiduously improved in the interest of economy and effectiveness as our vehicles of property or person.

T. C. C.

Reviews.

Fourteenth Annual Report of the New York State Geologist for 1894. JAMES HALL, State Geologist.

This volume of 669 pages, besides containing the short report of the state geologist giving an account of the work done under his direction, embraces several valuable papers upon the geology and palæontology of New York state. The brief reviews of these papers here given are taken largely from those written by the state geologist and printed in his report at the beginning of the volume.

1. *A Preliminary Description of the Faulted Region of Herkimer, Fulton, Montgomery, and Saratoga Counties.* By N. H. DARTON, pp. 31–56, Pls. I–IX, Figs. 1–12.

The field work upon which this paper is based was done in connection with the preparation of the geological map of the state. It describes in detail a region of country which was originally described by Vanuxem in his report on the geology of the Third District. It gives an account of the general relations of the faults, and describes in detail those at Little Falls, on the East Canada Creek, St. Johnsville, the Noses, Fonda, Tribes Hill, Broadalbin, Hoffman's Ferry, Saratoga, and Lake George.

The region is a general monocline with sediments of slightly varying dip, and the faults traversing this monocline, accompanied by certain features of local disturbance, have considerably modified its regularity. As a rule, these displacements do not make conspicuous features in the topography, but one of them, at Little Falls, gives rise to one of the most striking features in the scenery of the Mohawk valley.

2. *Report on the Structural and Economic Geology of Seneca County.* By D. F. LINCOLN, M.D., pp. 57–125, Pls. I–XIX, Figs. 1–30.

The subject treated in this paper is covered under three general divisions: (1) surface geology; (2) stratigraphic geology; (3) economic geology. Under the first head are given detailed accounts of the topography, and also of the superficial accumulations, their nature, and distribution. The sections on stratigraphic geology considers each formation in succession, from the Salina to the Portage, giving the local development and variations of each with fullness and precision. Faunal characters are touched upon to some extent, no wide difference in these respects from adjoining regions being noted. Under the head of economic geology are considered all the rock products of the county, their mode of exploitation, treatment, and economic value.

3. *The Principles of Palæontology.* By FELIX BERNARD. Translated by C. E. BROOKS, pp. 130–215.

This paper is extracted from Bernard's *Eléments de Paleontologie*, Paris, 1895, and is translated and here published for the benefit of American students to whom Bernard's entire works may not be accessible. No other writer has succeeded in setting forth so clearly the actual condition of the science, its relations to other departments of knowledge, and the inherent importance of the problems with which it is wholly concerned.

4. *Development and Mode of Growth of Diplograptus, McCoy.* By R. RUEDEMANN, pp. 217–258, Pls. I–V.

The observations recorded in this paper are based upon material in a remarkably perfect condition of preservation, obtained from the Utica slate at Dolgeville, N. Y. The paper shows that these graptolites, generally occurring as isolated stipes, were actually colonies composed of a large number of such individual stipes, growing radially from a center. The structure of the central part of the colony is shown to consist in (1) a central floating sack or pneumatocyst, demonstrating that the colony was unattached; (2) a verticil of spherical gonangia, within which are found masses of young graptolites or siculæ attached to a central axis; beneath the gonangia are (3) the radiately arranged graptolite stipes attached by long, bare extensions of the axial rod or virgula of each stipe. The paper is illustrated with five plates of highly instructive drawings.

5. *A Revision of the Sponges and Cœlenterates of the Lower Helderberg Group of New York.* By G. H. GIRTY, pp. 259–322, Pls. I–VII.

In this paper the known species of the groups mentioned are redescribed, with one new genus and ten new species. Four genera of sponges, with five species, are recorded, with thirteen genera and twenty-one species of cœlenterata.

6. *New Species of Brachiopoda described in the Palæontology of New York,* Vol. VIII, Parts I and II, 1872–1892. By JAMES HALL, pp. 323–402, Pls. I–XIV.

In this paper are published the descriptions of 106 species of brachiopoda, which were described incidentally and sometimes figured without descriptions in the recent work upon the class by Hall and Clarke.

7. *A Handbook of the Genera of North American Palæozoic Bryozoa.* With an Introduction upon the Structure of Living Species. By G. B. SIMPSON, pp. 403–699. Pls. A–E, I–XXV, and 222 figures in the text.

The first portion of this work is devoted to the recent bryozoa, and contains the history of observations upon these organisms from 1599 to the present time, followed by a bibliography and an illustrated detailed account of the anatomy.

The second part is devoted to the fossil forms from the Palæozoic rocks, and contains a scheme of classification, the bibliography of the Palæozoic species of America, a list of the genera and species described, with references to authorship and the geologic formations in which they occur. The genera described number 156, the species enumerated are about 1100. The main portion of the second part is devoted to diagnoses of the genera, illustrated by 222 figures in the text and by 25 plates.

STUART WELLER.

Petrology for Students, An Introduction to the Study of Rocks under the Microscope. By ALFRED HARKER, M.A., F.G.S. Second Edition, Revised. Cambridge, England, 1897.

A review of the first edition of this book by the present writer appeared in this JOURNAL, Vol. III, 1895, p. 856. The present edition reproduces the original text, with slight alterations, some of which follow the changes that appeared in the third edition of the second volume of Rosenbusch's *Mikroskopische Physiographie*, etc., published in 1896; besides the addition of numerous notices of American and Norwegian occurrences of various rocks, with references to their descriptions. The fuller mention of American occurrences increases greatly the value of the book for students in America, who will find it very useful for this reason.

The alteration in the title of the second group of igneous rocks, according to the classification followed in this book, namely, from that of Intrusive to that of Hypabyssal, has not obviated the necessity for the apology made in the introduction to this group of rocks in the first edition, which is repeated in the second. The newer term is as inappropriate as the former one, and the criticism made in the review of the first edition holds with equal force in the present case.

J. P. I.

Rocks, Rock Weathering and Soils. By G. P. Merrill. 8vo. 411 pp., Macmillan & Company, New York, 1897.

This admirable work brings together three subjects closely consecutive in the processes of nature but not previously associated as the subject of equally elaborate treatment in their mutual relations. The main emphasis of the work is placed on rock weathering, the description of rocks being in the main preliminary to this and that of soils a natural sequence. No attempt is made to treat rocks as such in an exhaustive way, nor soils as such. The discussion of weathering on the other hand is made as exhaustive as the present state of science will permit. The 168 pages of Parts 1 and 2 relating to minerals and rocks embrace a reasonably satisfactory treatment of these themes. This is as much perhaps as can be said of any attempt in this line in the present unfortunate condition of the classification and nomenclature of rocks and minerals. The relative fullness of treatment of the several rocks is measured in a degree by their importance in the production of soils. Very properly prominence is given to chemical composition, since this is a prime consideration in following the transition of the rocks into soils and secondary rocks. The numerous tables of analyses are a valuable feature. The use of terms is conservative and many of the intermediate stages in the gradation of one rock into another are left without specific nomenclature. The author files a protest against the tendency "which has resulted already in such monstrosities of nomenclature as *ouachitite*, *monchiquite*, *yogosite* and *absarokite*."

The subject of weathering and transportation occupies the heart of the book and constitutes its distinguishing feature. After a statement of the principles of weathering and of the agencies involved, the special modes of alteration of the leading rocks are discussed in detail. Perhaps the most valuable contribution of the book is the series of analyses of identical rock at varying stages of decomposition, by means of which the nature of the process, in so far as it is chemical, is specifically and precisely indicated. These tables show in just what degree the process acts differentially upon the several constituents of the rock. Although the analyses are not sufficiently numerous to warrant very broad generalizations, they are very helpful in giving approximate knowledge of the relative parts played by the several constituents of rock in the disintegrating process. The results of the analyses are conveniently indicated in separate columns which severally show the percentage of loss for the entire rock, the percentage of each constituent saved, and the percentage of each constituent lost. These special studies are followed by a résumé embracing general deductions drawn from them.

The chapter on the physical manifestations of weathering treats of the more familiar effects of the process on texture, color, surface configuration and similar features. This is followed by an interesting chapter on time considerations, in which are treated the rates of weathering and the influence of position, texture, composition, humidity, temperature and other climatic conditions upon the progress of the process.

The mantle of loose material which results from the weathering, together with loose material accumulated on the surface by other agencies, the author designates *regolith* (mantle rock), and devotes the last 100 pages to its description. It is not altogether clear whether the simple fact of mantling the surface with loose material is sufficient to unify accumulations arising from quite diverse agencies and varying greatly in nature, and hence to call for a specific name of the petrographic form. The residuary clays and earths constitute a unitary formation derived directly by the processes of weathering. The glacial, eolian, and similar deposits can only be brought into the same category by largely neglecting their mode of origin and confining attention merely to their superficial disposal and their incoherent character. It may well be questioned whether the genetic factor in these cases will not usually be the one to be kept at the front, and be more often placed in contrast to the residuary earths than merged with them. Doubtless, however, the mantling feature which they possess in common will make the term regolith often convenient. The word at any rate may be left to stand or fall as experience shall dictate.

The discussion of the soils is relatively less satisfactory than most other portions of the book, but this is a subject so large in itself that a satisfactory treatment could not be expected as a theme subordinate to so broad a subject as the central topic of the book.

The essence of several of the sections on weathering were published in this JOURNAL while the author was engaged upon the studies which have taken form in this book and its readers are familiar with the excellent method of their treatment and their substantial character.

C.

Authors' Abstracts.

PAPERS READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.[1]

Topography and Glacial Deposits of the Mohawk Valley. By Albert Perry Brigham.

The lower Mohawk, and a corresponding valley to the westward, are considered as subsequent in character, having been initiated by headward cutting from the ancient Hudson and St. Lawrence valleys, along the strike of soft beds, to the col located by Chamberlin at Little Falls. The Adirondack streams consequent on Palæozoic topography were thus diverted and the Susquehanna streams were beheaded. West of Little Falls the rock floor descends toward Lake Ontario, but not uniformly, a buried rock basin above 100 feet in depth, lying east of Utica. The present arrangement is due to glacial and aqueo-glacial erosion at Little Falls, and to aggrading from Rome eastward by glacial materials. The westward flow of the lower Mohawk glacier is confirmed by striation at Amsterdam.

The drift deposits west of Little Falls are largely composed of deltas and benches whose altitudes indicate approximately a water level of 600 feet. This is believed to represent a lacustrine stage in which the waters had fallen below the Warren level and below Fairchild's Geneva beach, but had not yet subsided to the Iroquois plane. The dam is thought to have been at Little Falls, and of a composite nature —the sill of gneiss then standing at about 440 feet, with drift and ice blockade, in this long, sinuous, narrow gorge. Below Little Falls, marginal bodies of massive till, aggraded by water-laid material, show a fluvio-lacustrine level of 430 to 440 feet, the barrier being unknown. The next stage in the lower valley was also fluvio-lacustrine, at 340 feet. The gneiss then caused a great waterfall at Little Falls, and the lacustrine stage persisted to the eastward, while a rock gorge more than

[1] Continued from last issue.

100 feet deep was cut at Aqueduct, near Schenectady. Certain beds of massive, water-laid clay west of Little Falls, taken with similar deposits in the Chenango and Unadilla valleys, are thought to show long and quiet deposition, with perhaps considerable later erosion, before the last advance of the ice across central and southern New York.

Clastic Huronian Rocks of Western Ontario and the Relations Between Laurentian and Huronian. By A. P. COLEMAN.

The rocks of the Lake of the Woods and Rainy Lake regions of western Ontario have been excellently mapped by A. C. Lawson, who calls them Archæan and subdivides them into a lower part, the Laurentian, and an upper one, the Ontarian, further subdivided into the Couchiching and the Keewatin. The Laurentian, which consists chiefly of granite and gneiss, underlies the other two series, but has an eruptive contact with them, showing that it was the latest in age. The Couchiching is formed mainly of fine-grained gray gneiss and mica schist, of clastic origin, since the quartz is usually in distinctly rounded grains. These rocks merge into almost unchanged sandstones in a few places, as found by the writer.

The Keewatin is much more varied, consisting very largely of basic and acid eruptives with their pyroclastics; but containing also important sedimentary members, such as limestone, slate, quartzite and conglomerate. The last rock is not a basal conglomerate resting on the Couchiching or Laurentian, but comes high up in the series, since it contains mainly pebbles of eruptives and schists found in adjoining portions of the Keewatin. It may represent a break equivalent to that between the lower and upper Huronian in the states to the south, as described by Van Hise. These conglomerates contain no Laurentian pebbles so far as known.

The field relations of the three formations are very interesting, both as mapped by Lawson and as observed on the bare shores of lakes in the western Archæan peneplain. The Keewatin, and in the southern part of the region the underlying Couchiching, form sharp synclines, curving as wide meshes round the areas of Laurentian, which vary greatly in size, running from a diameter of less than a mile to about fifty miles. Starting from the center of a Laurentian area one commonly finds first granite, then gneiss having a strike parallel to that of the adjoining schist. Before reaching the schist many fragments of it are usually seen embedded in the gneiss. Green Keewatin schists are generally turned to hornblende-schist near the contact, but the Couchiching mica-schists are seldom much altered. Dikes of granite or felsite frequently run from the Laurentian gneiss into the Ontarian or Huronian rocks, as they are generally called by Canadian geologists. We have evidently here a section through a pre-Cambrian mountain group, so near its base that some of the meshes run out as unfinished curves, erosion having eaten completely through them. From the steep dip of the schists in the synclines and the width of some of the Laurentian batholites we must infer that these dome-shaped mountains were of considerable height, probably comparable to the highest present ranges.

Lawson has computed the thickness of the two members of the Huronian (Ontarian) at about five miles each ; so that in some places 50,000 feet of sediments, in the upper part mixed with eruptives, must have rested on the old sea floor ; as great a thickness as we find in the sediments preparing the way for later mountain ranges.

This brought about a rise of the isogeotherms sufficient to produce hydrothermal fusion of the rocks underlying the sediments.

As the usual theory of mountain building, by lateral thrust, can produce only folds, these domed mountains must have been elevated in some other way. They may be compared with Gilbert's laccolites or I. C. Russell's plutonic plugs, or perhaps more nearly with the structure of the Black Hills, but present important differences from all of these types of mountains.

The writer suggests that the hydrothermally fused acid Laurentian magma was lighter, both because of its heat and specifically, than the overlying rocks; and so, by the laws of hydrostatics, slowly crept toward the points where the load was smallest, the heavier Huronian rocks sinking toward the lower portions, where they were ultimately nipped in as sharp synclines.

The region which typically displays this system of Huronian meshes enclosing Laurentian batholites is more than two hundred miles long and a hundred and twenty broad. How much farther similar conditions prevail cannot be known until the Canadian Archæan is more completely mapped than at present.

The Laurentian has been shown to form eruptive contacts with the Huronian eighty miles north of the Lake of the Woods, and in the Sudbury district, five hundred miles to the east. The Hastings series, as well as the Grenville series in eastern Ontario and Quebec, probably the equivalents in age of the western Huronian, show similar curving bands and eruptive contacts of the underlying Laurentian, as described by Adams, Barlow, and Ells; and the same is true, in part at least, of Labrador, as described by Lowe.

On the other hand, the Huronian regions in the United States south of Lake Superior, and also in New Brunswick, present a basal conglomerate resting unconformably on the Laurentian, according to Van Hise and Dawson. It may be that in the latter cases the thickness of sediments was not great enough to depress the Laurentian floor to the level of fusion or plasticity; or that the Huronian, as recognized in these regions, is really younger and overlies the upturned edges of the rocks described as Huronian in the northern Archæan. Some remarks in Van Hise's pre-Cambrian geology seem to suggest this.

It is likely that eruptive contacts of batholitic masses with overlying rocks exist under every great mountain chain; though the "Fundamental Complex" thus arising is disclosed only in the more ancient and therefore more deeply eroded mountain systems. Something like this has been shown to exist in British Columbia by Dawson, but of Jurassic age. Under the later mountain systems, however, the arching of anticlinal folds probably aided the uprising of the plastic base; and we may suppose that the core of granite and gneiss forms long belts rather than approximately round batholites.

The term Laurentian has been used in the paper to include granites and gneisses of later age than the Ontarian or Huronian rocks, following the custom of the Canadian geologists who have worked in western Ontario. As this use differs from Logan's original definition, it might be better to substitute another name, unless it shall appear that the relation described above is universal in North America, and that the supposed Huronian found to rest uncomformably on the Laurentian is really of later age than the true Huronian.

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CHEMICAL AND MINERAL RELATIONSHIPS IN IGNEOUS ROCKS.

The attempt to correlate the mineral composition of igneous rocks with the chemical composition of their magmas, that is, of each rock as a whole, is rendered difficult by the chemical character of the rock-making minerals themselves, and by the fact that no fixed association of minerals necessarily results from the crystallization of an igneous rock magma, the association in a given case being affected to a greater or less extent by the physical conditions attending the solidification of the magma.

The pyrogenetic rock-making minerals are mostly silicates of several elements which may enter in different proportions into the composition of distinct minerals; so that the chemical difference between a number of these minerals lies in the proportions of their chemical components rather than in the kinds. Among the more important rock-making minerals, including the chief silicates, together with quartz and magnetite, there is no element found only in one mineral. Each constituent may enter several of them. Nevertheless there are limitations to the kinds of elements constituting certain minerals, as well as more or less definite proportions to their amounts in each case. But it is to be remembered that with the exception of quartz none of them has an absolutely fixed composition, but each belongs to an isomorphous or morphotropic series, that is, represents a more or less variable mixed salt or crystal. Variations in the chemical constituents of rock magmas will affect the chemical composition of several minerals in any case, as well as the relative proportions of all the minerals constituting the rock.

The relations between the minerals crystallized from a rock magma and the physical conditions attending its solidification have been scarcely more than recognized in a general way, though many examples have become well known. But enough has already been learned to warrant the conclusion that the attendant physical conditions exert a definite control over the grouping of the chemical elements in the molten magma, whereby the kind and character of the minerals crystallizing from it are affected. And it may be confidently predicted that careful comparison of the chemical composition of rocks with their exact mineral composition and texture, and with their mode of occurrence as geological bodies, will eventually lead to the discovery of these relationships.

Realizing the difficulties in the way of a complete correlation of the mineral and chemical composition of igneous rocks, and the limitations of our present knowledge both as to the relationships just mentioned, and as to the actual chemical composition of many rock-making minerals, it may still be possible to make a beginning of the correlation by attempting to state certain relationships between the theoretical molecules of the chief rock-making minerals and the chemical composition of igneous rock magmas.

Composition of the rock-making minerals.—Owing to the com plexity of even this preliminary correlation, it is advisable to consider only the more important rock-making minerals, leaving the less frequent ones for future elaboration of the discussion. The former may be grouped as follows: Quartz, the feldspathic minerals: the feldspars proper, with leucite, nephelite and the sodalites; muscovite, forming a link between feldspathoid minerals and ferromagnesian minerals; biotite and the other ferromagnesian minerals: olivines, pyroxenes, amphiboles; besides magnetite. Minerals necessary to a fuller discussion are melilite, garnet, titanite, perofskite, apatite, zircon, and others.

The chemical composition of each of these minerals, or groups of minerals, may be expressed in the simplest form, as in the following list, first by the empyrical formulas, second by the dualistic, the convenience of the latter being apparent when comparison is made with the chemical composition of the rocks, as expressed in the usual statement of analyses.

Quartz,	SiO_2	SiO_2
Orthoclase,	$KAlSi_3O_8$	$K_2O.Al_2O_3.6SiO_2$
Soda-orthoclase, Soda-microline,	$(K,Na)AlSi_3O_8$	$(K,Na)_2O.Al_2O_3.6SiO_2$
Albite,	$NaAlSi_3O_8$	$Na_2O.Al_2O_3.6SiO_2$
Oligoclase, Andesine, Labradorite,	m $(NaAlSi_3O_8)$ n $(CaAl_2Si_2O_8)$	
Anorthite,	$CaAl_2Si_2O_8$	$CaO.Al_2O_3 2SiO_2$
Leucite,	$KAlSi_2O_6$	$K_2O.Al_2O_3.4SiO_2$
Nephelite,	$KAlSi_2O_6$ n $(NaAlSiO_4)$	
Soda-nephelite,	$NaAlSiO_4$	$Na_2O.Al_2O_3.2SiO_2$
Sodalite,	$Na_4(AlCl)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2NaCl$
Hauynite,	$Na_2Ca(NaSO_4.Al)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2CaSO_4$
Nosite,	$Na_4(NaSO_4.Al)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_3]+2NaSO_4$
Muscovite	$KH_2Al_3Si_3O_{12}$	$(K,H)_2O.Al_2O_3.2SiO_2$
Biotite,	$(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ or $2[(H,K)(Al,Fe)SiO_4]$ $(Mg,Fe)_2SiO_4$	 $2[(H,K)_2O.(Al,Fe)_2O_3.2SiO_2]$ $2(Mg,Fe)O.SiO_2$
Olivine,	$(Mg,Fe)_2SiO_4$	$2(Mg,Fe)O.SiO_2$
Pyroxenes		
Enstatite,	$Mg_2Si_2O_6$	$MgO.SiO_2$
Hypersthene,	$(Mg,Fe)_2Si_2O_6$	$(Mg,Fe)O.SiO_2$
Diopside,	$CaMgSi_2O_6$	$CaO.MgO.2SiO_2$
Salite,	$Ca(Mg,Fe)Si_2O_6$	$CaO.(Mg,Fe)O.2SiO_2$
Augite,	$Ca(Mg,Fe)Si_2O_6$ $(Mg,Fe)(Al,Fe)_2SiO_6$	$CaO(Mg,Fe)O.2SiO_2$ $(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$
Acmite,	$NaFeSi_2O_6$	$Na_2O.Fe_2O_3,4SiO_2$
Amphiboles		
Hornblende,	$Ca(Mg,Fe)_3Si_4O_{12}$ $(Mg,Fe)_2(Al,Fe)_4Si_2O_{12}$ $Na_2,Al_2Si_4O_{12}$	$CaO.3(Mg,Fe)O.4SiO_2$ $(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$ $Na_2O.Al_2O_3.4SiO_2$
Arfvedsonite,	$(Na_2,Ca,Fe)_4Si_4O_{12}$ $(Ca,Mg)_2(Al,Fe)_4Si_2O_{12}$	$(Na_2,Ca,Fe)O.SiO_2$ $(Ca,Mg)O.(Al,Fe)_2O_3.SiO_2$
Riebeckite,	$Na_2Fe_2Si_4O_{12}$ $FeSiO_3$	$Na_2O.Fe_2O_3.4SiO_2$ $FeO.SiO_2$
Magnetite,	Fe_3O_4	

From this it will appear into how many different molecules any chemical element many enter. In order to simplify the problem further, the several kinds of molecules may be presented in the following manner:

Elements	Kinds of molecules		Kinds of minerals
K, Na, Al,	$(K,Na)_2O:AlO_3:SiO_2$ ::	1:1:6	orthoclase, albite
		1:1:4	leucite (amphibole)
		1:1:2	nephelite, sodalite(with excess of Na.)
	$(K,H)_2O:Al_2O_3:SiO_2$ ::	1:1:2	muscovite ($Al_2O_3 > K_2O$)
K, Na, Al, Fe,	$(K,H)_2O:(Al,Fe)_2O_3:SiO_2$ ::	1:1:2	mica (biotite)
Na, Fe,	$Na_2O:Fe_2O_3:SiO_2$ ::	1:1:4	acmite, riebeckite
Na, Fe, Ca,	$(Na_2,Ca,Fe)O.SiO_2$		arfvedsonite
Ca, Al,	$(CaO:Al_2O_3:SiO_2$ ::	1:1:2	anorthite
Ca, Mg, Fe,	$CaO.(Mg, Fe)O.2SiO_2$		pyroxene
	$CaO.3(Mg, Fe)O.4SiO_2$		amphibole
Mg, Fe,	$(Mg,Fe)O.SiO_2$		pyroxene
			olivine, mica
Mg, Fe, Al,	$(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$		pyroxene, amphibole

The alkalis combine with an equal number of molecules of alumina in the feldspathic minerals (except sodalites). These are polysilicates, metasilicates and orthosilicates; also in one of the amphibole molecules; while in muscovite part of the potassium is replaced by hydrogen. The alkalis with hydrogen enter into an orthosilicate, mica molecule with alumina and ferric oxide in the proportion of 1 : 1, the potash being generally less than alumina. Soda enters into a metasilicate molecule with ferric oxide, in the acmite molecule. It combines with lime and ferrous oxide in the metasilicate, arfvedsonite molecule. Calcium oxide enters an orthosilicate molecule with alumina in proportions of 1 : 1. — anorthite. Calcium occurs with magnesium and iron in metasilicate molecules in pyroxenes and amphiboles, which differ in the relative proportions of CaO:(Mg, Fe)O; in the first case in the ratio 1 : 1; in the second, 1 : 3. Magnesium and ferrous iron usually occur together in variable proportions, either in a metasilicate molecule with calcium in monoclinic pyroxenes and amphiboles, or without calcium in metasilicate molecules in orthorhombic pyroxenes, or in orthosilicate molecules in olivine and mica. They combine with aluminium and ferric iron in a subsilicate molecule in pyroxenes and amphiboles. Magnesium may occur without iron in metasilicate molecules, in diopside with calcium, and in enstatite without calcium. The alkali-alumina silicates may be polysilicates, metasilicates or orthosilicates. The ferromagnesian silicates may be metasilicates, orthosilicates or subsilicates. Iron may occur uncombined with silica in the form of magnetite, and silica may occur uncombined with other elements in the form of quartz or tridymite.

Preliminary correlation.— Some of the more evident relationships between the pyrogenetic minerals in igneous rocks and the chemical composition of the magma have been stated in a previous article in this volume.[1] They are : the usual occurrence of quartz with the polysilicate feldspars, and its non-occurrence with the meta- and orthosilicate feldspathic minerals : leucite, nephelite and sodalite ; also the relation between these and the percentage of silica in the rock — the highest of these silicates always forming which is possible with the available silica in the magma. Another law seems to be that the alkalis control an equal amount of alumina, forming alkali-feldspathic molecules, and that aluminium in excess of this may combine with calcium to form anorthite molecules, or with magnesium and iron to enter pyroxene and amphibole molecules. Soda does not seem to unite with ferric oxide to enter pyroxenes or amphiboles in any considerable amount unless it is in excess of alumina. The metasilicate, orthorhombic pyroxenes, hypersthene and enstatite, usually occur in the more siliceous rocks instead of the orthosilicate, olivine, which usually occurs in the less siliceous rocks. But this is not an invariable rule, and olivine occasionally occurs in the more siliceous rocks (dacite) and not unfrequently in the presence of quartz. The orthosilicate, mica, commonly occurs in highly siliceous rocks together with quartz ; pyrogenetic muscovite exclusively so. Biotite also occurs in rocks low in silica. Its range of occurrence bears no fixed relation to the percentage of silica in the rock. Magnetite occurs in rocks of all degrees of siliceousness and is not directly dependent on the

[1] On Rock Classification, JOUR. GEOL., Vol. VI, pp. 96–98.

amount of silica in the magma. It frequently occurs in association with quartz or tridymite. It is a general law that the ferromagnesian minerals become more abundant as the quartz and feldspathic minerals become less abundant.

A method of correlating the chemical and mineral composition of igneous rocks on a basis of the silica percentage and of the relative amounts of alkali in each case has been presented in the article in this volume[1] already cited. It is now proposed, without repeating what has been stated in that connection, to discuss in greater detail some of the relations between the mineral and chemical constituents of igneous rocks by making use of similar diagrams. In order to do this it will be necessary to start with the simplest assumptions, and those that appear to rest on the more general laws. Having obtained some of the simpler conceptions, more complex ones may be attempted with less danger of confusion.

It is possible to obtain an idea of the range of quartz and of leucite, nephelite and sodalite in igneous rocks by considering the most favorable cases for their occurrence, and afterwards the conditions that would modify their production. In order to render the discussion as simple as possible it is advisable to consider the extreme cases in which the alkali is either wholly soda or wholly potash. In Diagram 1 the black spots represent the rocks in which the soda is more than twice as great as potash, and the red spots those in which the potash is greater than soda. They correspond to the spots on Diagrams 2 and 4, Plates I and II of this volume. They are introduced to aid the imagination. The significance of the lines is explained in the text. For the phrase "the analysis or analyses of rocks" in the discussion of the diagrams the phrase "the rock or the rocks," will be substituted, it being understood that only the chemical attributes of the rocks are under discussion.

I. Let us first postulate the case of magmas whose *alkali is wholly soda*, and in which the *molecules of alumina are always in equal proportions to those of soda.* Then with no other constituent

[1] Loc. cit., pp. 98–103.

except varying percentages of silica the resulting rocks if wholly crystallized would consist of orthosilcate of sodium and aluminium, nephelite; this with polysilicate of the same elements, albite; albite alone; or albite and quartz, according as silica is lower or higher. We may say the rocks would lie on the curved line *QAN*. The point *Q* is where pure quartz occurs; and the point *A* where pure albite occurs; and *N* where soda-nephelite occurs. Pure albite rock would occur at *A*. Any rock on the line between *A* and *N* would consist of albite and soda-nephelite in proportions varying from one extreme to the other. Any rock on the line between *A* and *Q* would consist of albite and quartz in proportions varying in the same manner.

From *A* as a point of departure let us consider what must be the composition of soda-alumina rocks not occurring on the line *QAN*. If we consider magmas with constant alkali-silica ratios, namely .166, it is evident that proceeding from *A* horizontally, as the silica percentage becomes less, the soda and alumina must also become less, consequently the sum of these constituents will not be 100, which is always the total of the percentages in any case. There must therefore be other chemical constituents besides Na_2O, Al_2O_3 and SiO_2. The same is true if we proceed from *A* vertically downwards, that is, if we consider magmas having the same silica percentage, namely 68.7, for with decreasing alkali-silica ratios there will be less soda and alumina, and the sum of Na_2O, Al_2O_3, SiO_2 will not be 100. The same will be true if we proceed in any direction from *A* below the line *QAN*.

All rocks except those occurring upon this line must contain other constituents than Na_2O, Al_2O_3, SiO_2. These may be CaO, MgO, FeO, Fe_2O_3 (potash being excluded by the initial assumption). Let us assume them to be either CaO, MgO, FeO, singly or together, and that they occur as silicates. The case of $FeO.Fe_2O_3$, magnetite, will be considered subsequently. It having been assumed that alumina is present only in proportions to satisfy soda, the possibility of the formation of an aluminous molecule with these constituents will be excluded for the present. The silicates capable of forming from CaO, MgO and FeO are orthosilicates and metasilicates; olivine, 2(Mg,Fe)O. SiO_2, with its theoretically possible extremes $2FeO.SiO_2$ (fayalite) and $2MgO.SiO_2$ (fosterite); orthorhombic pyroxenes, enstatite, $MgO.SiO_2$, and hypersthene, (Mg,Fe)$O.SiO_2$, and the monoclinic pyroxenes, diopside, $CaO.MgO.2SiO_2$, and salite, CaO.(Mg,Fe)$O.2SiO_2$. It is possible to introduce into the composition of a magma such as already postulated one or more of these molecules in such proportions as to make the sum of all equal to 100. But it is clear that the development of a silicate of any of these kinds in the magma would affect the distribution of the silica among the other molecules, that is, it would affect the relative porportions of albite and nephelite or of albite and quartz. It is possible to discover by simple algebra what would be the range of percentages of silica and the range of the alkali-silica ratio for a series of rocks composed wholly of albite and any one of the calcium, iron, magnesium molecules just mentioned. This range will be expressed by a curved line on the diagram extending from the point *A* to the point corresponding to the locus in the diagram of the pure molecule under consideration. Several of these lines are indicated on Diagram 1. The most extreme case, most favorable to the presence of albite is that in which it occurs in combination with $2FeO.SiO_2$, orthosilicate of iron. The range is indicated by line *AFa*, which shows the alkali-silica ratios necessary in order that a rock should consist wholly of albite and Fe_2SiO_4. Any rock occurring above this line and containing only the constituents Na_2O $=Al_2O_3$, FeO, SiO_2 would have relatively too little silica to form albite out of all the soda and alumina and would contain some nephelite. That is, all rocks of this kind occurring above the line *AFa* would carry nephelite, even those having alkali-silica ratio $=.03$, if $SiO_2 = 31$. Conversely, all rocks occurring below this line would have relatively too much silica to convert all the soda and alumina into albite and there would necessarily be quartz, if FeO alone formed an orthosilicate, which is the case in hand. Quartz would thus be a necessity in rocks with only 35 per cent of SiO_2 when the alkali-silica ratio is less than .045. For a combination of albite and $2MgO.SiO_2$ the range is shown by the line *AFo*, and for a combination of albite and olivine, $2(Mg,Fe)O.SiO_2$, in which Mg: Fe:: 3:1, the range is *AOl*. From this it is seen that if orthosilicate of magnesium accompanies that of iron the nephelite limit will advance toward the left, that is, in the direction of higher silica percentages, and the quartz limit will recede in the same direction.

In case iron and calcium or magnesium occur as metasilicates the range of possible combinations of these with albite is shown by the lines *AF*, *AC*, *AM*. If magnesium and iron occur together in equal proportions, as in some hypersthene, the line nearly coincides with *AC*. So also if the metasilicate has the composition $CaMgFeSi_3O_9$, or $Ca_2MgFeSi_4O_{12}$ (a diopside) or $Ca_2Fe_3Mg_3Si_8O_{24}$ (actinolite molecule in amphibole) the range would coincide with the same line. An increase of magnesium would move the line to the left toward *AM*. The range of positions for diopside is indicated by the bracket in the diagram. The range of positions for enstatite would lie to the left of this for the most part. From this it appears that rocks having soda and alumina in equal amounts together with metasilicates of iron, magnesium and calcium, if they occur to the right of the limits just described would necessarily contain nephelite, and if they occur to the left of these limits they must contain quartz. Since metasilicates are the highest silicate of these elements occurring in igneous rocks it follows that no other ferromagnesian molecule may be postulated which will appropriate more silica from the magma. Hence the most favorable case, namely that involving the highest silicate of alkali and alumina and the highest of calcium, iron, and magnesium, requires the presence of quartz in all holocrystalline rocks occurring to the left of these lines. In actual fact the three elements just named usually occur in somewhat similar proportions, so that the position of the line *AC* represents the limit of quartz in the ordinary case most favorable to its scarcity. Any combination of orthosilicate will tend to move the quartz limit still further toward the right, in the direction of lower silica percentages. Quartz must therefore occur in rocks with lower and lower silica in proportion as the alkali-silica ratio decreases, and as lower silicate molecules are developed instead of higher silicates. The line *AC* is probably very near the highest limit of *no quartz* to be found in holocrystalline igenous rocks.

If any of the iron crystallizes as magnetite instead of combining with silica to form ortho- or metasilicates, silica will be liberated to form more albite out of nephelite, or to produce more quartz by the side of albite. The effect of the development of magnetite then is to shift the quartz-nephelite limit farther to the right, that is, toward lower silica percentages. In the case of rocks within the nephelite limit, the effect will be to decrease the nephelite and increase the albite. It may also react upon the ferromagnesian silicates when orthosilicates are present, permitting the liberated silica to convert some of the orthosilicates into metasilicates without materially affecting the relative proportions of the other constituent minerals.

In this connection attention may be called to the line *NFa*, which is the range of magmas composed wholly of nephelite and the orthosilicate of iron. It appears to be the limit toward which the highly sodic magmas tend, as may be seen in Diagram 1. Magmas low in alkalis associated with the eruptive iron ores lie beyond this boundary.

II. In order to discover the relations that would obtain for magmas in which *the alkali is wholly potash* when *alumina is present in amounts just equal to the potash*, we have to consider the range of positions for rocks corresponding to mixtures of quartz and orthoclase (potassium-aluminium polysilicate), and of orthoclase and leucite (potassium-aluminium metasilicate). This corresponds to the red line *QOL*. As already remarked in the previous paper, the lowest potassium-aluminium silicate among the feldspathoid minerals appears to be the metasilicate, leucite, and when potassium is found in rock-making nephelite it may be explained as in a metasilicate molecule mixed with the sodium-aluminium orthosilicate. If we conduct the discussion in the same manner as in the previous case we should proceed from the point *O*, the position for a pure potash-orthoclase rock. At this point the alkali silica ratio =.166 and SiO_2=64.7. Rocks consisting of pure orthoclase and leucite will occur along the line *OL;* those composed of pure orthoclase and quartz along the line *OQ*. Rocks having an alkali-silica ratio of .166 and less than 64.7 per cent. of silica must contain some other constituents than K_2O=Al_2O_3 and SiO_2. The same is true for all rocks lying below the line *QOL*. The range of rocks that might consist of pure orthoclase and orthosilicate of iron is shown by the red line *OFa*, close to the corresponding line for soda magmas. All rocks occurring above this would necessarily contain leucite, all below it would contain quartz. The lines *OOl* and *OFo* represent the range for rocks consisting respectively of orthoclase and olivine, and of orthoclase and orthosilicate of magnesium. They also mark the limit of the quartz-bearing rocks of this kind on one side, and of leucite rocks on the other. The lines for rocks composed of orthoclase and metasilicates of iron, magnesium and calcium are *OF*, *OC*, *OM*. They are somewhat further from the corresponding ones for soda magmas than in the case of the orthosilicates. Comparing their positions with those of the corresponding lines for soda magmas, it is seen that the quartz limit is lower in the scale of silica percentages for potash magmas than for soda magmas. That is, other things being equal, quartz will occur in less siliceous potash rocks than in the corresponding soda rocks, the most marked differences being in rocks highest in alkalis.

The development of magnetite would have the same effect in shifting the quartz-leucite limits toward the right, that is, toward rocks with lower silica percentages as in the case of soda magmas. The line *LFa* is the range for magmas composed of leucite and orthosilicate of iron and seems to be the lowest limit for potash magmas, as stated on page 102 of this volume.

Magmas in which both soda and potash occur with equal amounts of alumina would behave in a manner analagous to that just described for either extreme, the feldspars would be soda-potash polysilicates, with quartz or with leucite or nephelite. The lines indicating the range of combinations of feldspar and ferro-magnesian silicates would occupy positions intermediate between the corresponding lines for albite and for orthoclase. The quartz-leucite-nephelite limits would be nearly the same as before.

III. Let us now postulate the case of magmas in which the *alkalis control an equal amount of alumina* and in which *lime and additional alumina occur in the proportion of one to one* and *constitute orthosilicate, anorthite molecules.* First, let all of the alkali be soda. This case is illustrated by Diagram 2. As the relative proportions of the constituents, $Na_2O=(Al_2O_3)'$, $CaO=(Al_2O_3)''$ and SiO_2 vary, those rocks in which there is soda and no lime will consist of albite and quartz, or of albite and nephelite, and will occur along the line *QAN*, Diagram 2, as in the previous Diagram 1. All rocks occurring below this line will contain anorthite molecules in variable proportions. Pure anorthite rock will occur at the point *An*, where the alkali-silica ratio $=0$, and $SiO_2=43.2$. The range of rocks composed wholly of albite and anorthite in varying proportions will occur along the line *AAn*. They correspond to rocks each consisting of a feldspar of the albite-anorthite series. The points on this line at which particular mixtures occur, such as Ab_6An_1, $Ab_2\ An_1$, etc., are designated in the diagram. This line also indicates the range of rocks consisting wholly of soda-lime-feldspar. All rocks from magmas of this case, III, to the right of this line must contain nephelite in addition to these feldspars. All rocks to the left must contain quartz, the argument being the same as for magmas of cases I and II. Assuming that the feldspar present is always one corresponding to the particular combination of albite and anorthite molecules in the magma, we may discover the range of magmas consisting of combinations of each of these kinds of feldspar and quartz on the one hand, and of these and nephelite on the other. They are indicated by the lines *QA*, *Qb*, . . *QAn* and *NA*, *Nb*, . . *NAn*, which also indicate the limits for magmas of this kind. None would be possible to the right of the line *NAn*, unless containing other elements than those already mentioned for this case, III.

Since within the boundaries *QNAn*, rocks may exist composed wholly of quartz and the feldspathic minerals mentioned, the presence of any ferromagnesian compound necessitates the diminution of some of the first-named constituents, and since the silica percentages and alkali-silica ratios are the coördinates by which comparisons are made, we may assume that the presence of ferromagnesian constituents affects the lime and its equivalent alumina. Let them be affected equally. The orthosilicate anorthite molecules may then be replaced in some uniform manner by non-aluminous ferromagnesian orthosilicates or metasilicates. If the anorthite molecules be replaced by orthosilicate of iron, Fe_2SiO_4, the varying results are indicated in Diagram 2. If wholly replaced by Fe_2SiO_4, the line *AFa* would represent the range of the resulting rocks composed of varying proportions of albite and Fe_2SiO_4. And the area *AFaAn* would be the range of rocks composed of varying proportions of albite and Fe_2SiO_4 and anorthite. The lines *bFa*, *cFa*, etc., indicate the ranges of rocks composed of Fe_2SiO_4 and Ab_6An_1, Fe_2SiO_4 and Ab_2An_1, etc. That is, ranges in which the character of the lime-soda feldspar is constant, but the proportions of Fe_2SiO_4 vary. The line *Ay* shows the range of rocks composed of albite, with varying amounts of anorthite and Fe_2SiO_4 in the proportion of 4 to 3. At the points *b'*, *c'*, *d'*, etc., where this line intersects the lines *bFa*, etc., the rocks would consist of Fe_2SiO_4 and the feldspars Ab_6An_1, Ab_2An_1, etc. From this it is evident that as the molecules of anorthite are replaced by ferromagnesian molecules, the feldspars in a rock of any given silica percentage and alkali-silica ratio become relatively higher in albite molecules, that is, the lines *Ob*, *Oc*, etc., would shift farther from *QA*; more sodic feldspars would occur in rocks with lower alkali-silica ratios. There would be a similar movement of the lines *Nb*, *Nc*, etc., away from *NA;* more sodic feldspars would be found in rocks lower in silica.

If the anorthite molecules be replaced by orthosilicates of iron, or of iron and magnesium, less silica would be required than before, and the quartz limit would shift to the right. If they were replaced by metasilicates of iron, magnesium or calcium, more silica would be required, and the quartz limit would shift to the left. If both were developed together the quartz limit might remain nearly as before. If magnetite were developed the effect on the quartz limit would be still more marked, and it would be shifted still farther in the direction of lower silica percentages.

Second, let all of the alkali be potash. Assuming that in this case there would be two distinct kinds of feldspar present, potash-orthoclase and anorthite, the range of rocks consisting wholly of these two minerals in variable proportions would lie along the red line *OAn*, Diagram 3, and the line *QOL* would be the range of rocks of this kind free from anorthite. All rocks of this kind occurring to the right of the line *OAn* must contain leucite; all those to the left must contain quartz. The effect of replacing anorthite molecules by ferromagnesian molecules would be similar to that just stated for the albite-anorthite magmas; however, orthoclase not being combined with anorthite, would remain as before except where changes in the silica affected the orthoclase molecules by reducing them to leucite or affected the leucite molecules by raising them to orthoclase. This would occur in the neighborhood of the line *OAn*.

Third, if soda and potash were both present, other things being the same as postulated in the general statement of case III, it is evident that the range of rocks that might consist wholly of feldspars, either pure albite, pure orthoclase, or pure anorthite, or any possible mixture of these, would be within the area *AOAn*, Diagram 3. This narrow area would be the boundary between the quartz range on one side and the leucite-nephelite range on the other. The effect on the albite-anorthite feldspar, whose character would be that previously indicated if all the alkali were soda, by the partial replacement of soda by potash would be to render it lower in the scale toward the anorthite end, so that the amount of orthoclase would be increased and the accompanying lime-soda-feldspar would be more calcic. This is indicated in Diagram 3. As potash replaces soda, the extreme limit of pure alkali-alumina silicate would shift along the line *NL* toward *L*. When they are in equal amounts the limit would be at *P*. At the same time, the range of rocks consisting wholly of anorthite, with albite and orthoclase in equal proportions, would be indicated by the line *xAn*. The points *b′*, *c′*, *d′*, etc., on it are where the lime-soda feldspar would have the value of Ab_6An_1, Ab_2An_1, Ab_1An_1, etc. The red lines connecting these points with *P* on one side and with *Q* on the other represent the range of rocks composed wholly of these particular lime-soda feldspars and leucite-nephelite on the one hand, and of these feldspars and quartz on the other. The replacement of anorthite molecules by ferromagnesian ones will have the same effect as that just stated for each extreme of alkali-lime-feldspar magmas.

IV. There remains to be discussed the modifications that would be effected in the feldspathic magmas already postulated by the introduction of ferroaluminous molecules. These may be of two kinds: ferromagnesian-ferroaluminous molecules, appearing in pyroxenes and amphiboles, with the general formula $(Mg,Fe)(Al,Fe)_2SiO_6$; and alkali-ferroaluminous molecules, occurring in mica, amphiboles, and pyroxene. Among these are molecules free from ferric iron, and others free from aluminium. They are $KH_2Al_3Si_3O_{12}$, $(K,H)(Al,Fe)SiO_4$, $NaAlSi_2O_6$, $NaFeSi_2O_6$.

Let us first consider those free from alkalis. Upon the general assumption that the alkalis control an equal amount of alumina, the introduction of ferromagnesian-ferroaluminous molecules would demand an increase in the alumina over that necessary to satisfy the alkalis. This must take place at the expense of the ferromagnesian and calcium molecules in cases I and II, or at the expense of anorthite molecules, in case III.

Let us consider cases I and II. The molecule (Mg,Fe)(Al, Fe)$_2$SiO$_6$ is a subsilicate. The range of silica percentages for all manner of variations in its composition is from 29.52 for $MgAl_2SiO_6$ to 20.54 for $FeFe_2SiO_6$. The molecule usually is more nearly the average of these extremes. The silica range is indicated in Diagram 1 by the bracket, which shows that this molecule requires less silica than the orthosilicate of iron, considerably less than olivine, and very much less than diopside or enstatite. Its development, then, would extend the quartz limit and reduce the nephelite-leucite limit very considerably in proportion to its own amount. It may be stated that in general its amount is quite subordinate to that of the ferromagnesian ortho- and metasilicates. Its effect on magmas of case III, where anorthite occurs, would be of the same kind as the introduction of non-aluminous ferromagnesian silicates, but the degree of the change would be greater in proportion to the number of molecules introduced.

Turning to the alkali-ferroaluminous molecules, it is to be observed that one, (K,H)(Al, Fe)SiO$_4$, is well known to be capable of appearing in igneous rocks of almost any chemical composition in which its elements occur. Two others (K,H) AlSiO$_4$, and $NaFeSi_2O_6$ appear to occur in rocks with special chemical composition, while the fourth, $NaAlSi_2O_6$, is less well known but may be supposed to be of wide occurrence in small amounts. The first belongs to biotite. If the ratio between potassium and hydrogen varies from 1 : 1 to 1 : 2, and the aluminium and iron be supposed to reach their possible extremes, from normal biotite to lepidomelane, the range in silica percentage for this orthosilicate molecule would be from 29.07 to 19.10, which is indicated by the bracket in Diagram 1. The relative proportions of potash and alumina vary from 1 : 1 to 1 : 2 in most instances. Sodium does not enter into the molecule to any considerable extent, the development of biotite then affects the potash-feldspathic molecules. In orthoclase rocks within the quartz limit its development would reduce the amount of orthoclase molecules, and would change a polysilicate into an orthosilicate and liberate silica, increasing the amount of quartz or raising ferromagnesian orthosilicates to metasilicates. But the development of biotite would draw upon the ferromagnesian orthosilicate $(Mg,Fe)SiO_3$, reducing the amount that might be converted into metasilicate. The quartz limit would then be shifted toward lower silica percentages. In orthoclase-leucite rocks, or leucite rocks without orthoclase, the development of this potash-ferroaluminous molecule would reduce the amount of these minerals and liberate silica, which would raise the metasilicate leucite to orthoclase. The effect would thus be to cause the leucite limit to recede toward lower silica percentage.

It has already been noted that the development of biotite involves, besides the potash-bearing molecule under discussion, an orthosilicate of iron and magnesium, which is the same as an olivine molecule. The development of this molecule in rocks that might otherwise carry ferromagnesian metasilicate molecules would still further liberate silica, to appear as more quartz or raise more leucite to orthoclase.

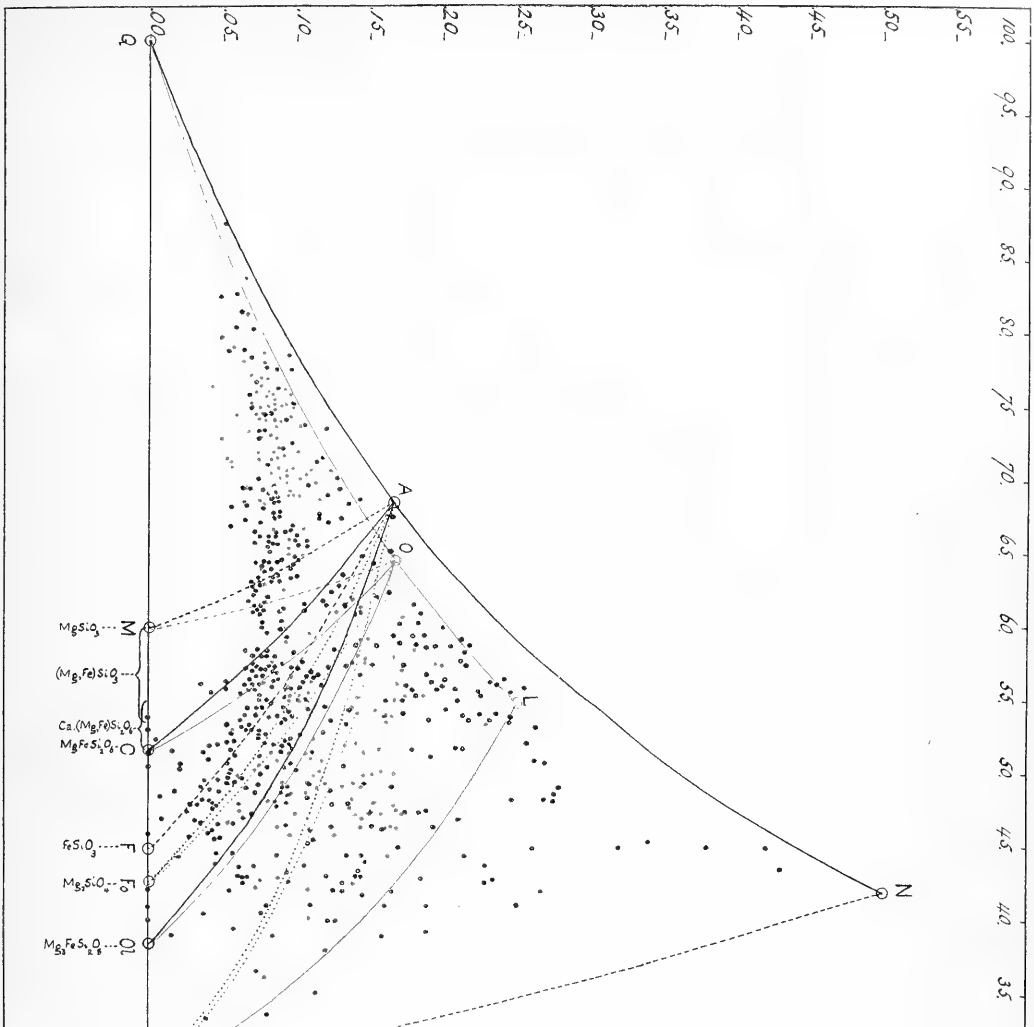
In case alumina is in excess of potash in this mica molecule the excess of alumina must be drawn from an excess of alumina over the alkalis originally in the rock, or it must be drawn from a sodium-aluminium molecule, since no potash molecule, in which potash exceeds alumina, occurs to any extent in the pyrogenetic minerals according to present theories. In the second instance the effect would be to reduce the albite or nephelite molecules and drive the soda into combination with ferric iron, affecting the distribution of the silica.

The development of the metasilicate molecule, $NaAlSi_2O_6$, which enters amphibole, would reduce the albite molecules with the liberation of silica and the possible production of quartz, or the raising of nephelite to albite. It would reduce the nephelite molecules if it did not affect those of albite, and would require additional silica, which would have to be drawn from a polysilicate (orthoclase) or from a metasilicate. It does not appear to enter largely into the composition of rock-making amphiboles, except possibly into those crystallized from magmas rich in soda and alumina.

The molecule (H,K) $Al Si O_4$, with little or no iron and with hydrogen and potassium, usually in the proportion of 2:1, occurs as muscovite. It is nearly identical with that occurring in biotite, except for lower iron. Muscovite occurs as a pyrogenetic mineral only in the most highly siliceous and quartzose rocks, where it is sometimes accompanied simply by quartz and alkali feldspar. The fact that this molecule often carries three times as much alumina as potash, and the absence of other potash molecules in which potash occurs in greater amount than alumina, indicates that the muscovite molecule develops in magmas in which alumina is in excess of the alkalis. Its presence bears no direct relation to the percentage of silica in the rock. Its absence from many rocks in which alumina is in excess of alkalis is probably due to its combination with iron and magnesia, resulting in the formation of biotite. Magmas sometimes occur with so large an excess of alumina that it crystallizes as corundum, Al_2O_3, in association with alkali-feldspars. The alumina in these cases did not enter muscovite molecules with the potash.

The development of the sodium-iron-metasilicate, $Na Fe Si_2 O_6$, which occurs in pyroxene, as the acmite molecule, and also in riebeckite, is pronounced in magmas rich in sodium and ferric iron; Fe_2O_3 appearing to take the place of Al_2O_3. Considered in connection with the composition of rocks of case I and III, Diagrams 1 and 2, its presence reduces the amount of albite, and increases the silica available for quartz or for raising nephelite molecules to albite according to the position of the rock in the scheme. Its presence would therefore shift the quartz limit toward lower silica percentages. It does not appear to play any considerable rôle in rocks low in soda or in ferric oxide.

It is not the plan of the present paper to discuss the effect on the mineral composition of rocks of the development of the less abundant or subordinate minerals. In some cases their production is clearly due to the presence of special elements,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$(Mg,Fe)SiO_3$
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$MgFeSi_2O_6$
$FeSiO_3$
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DIAGRAM I.

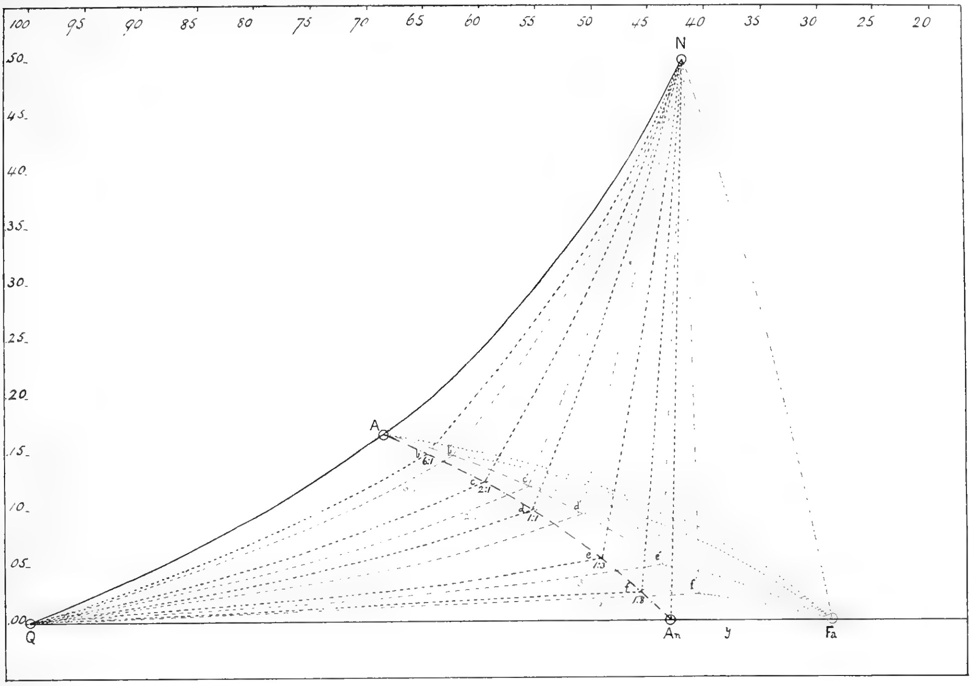


Diagram 2

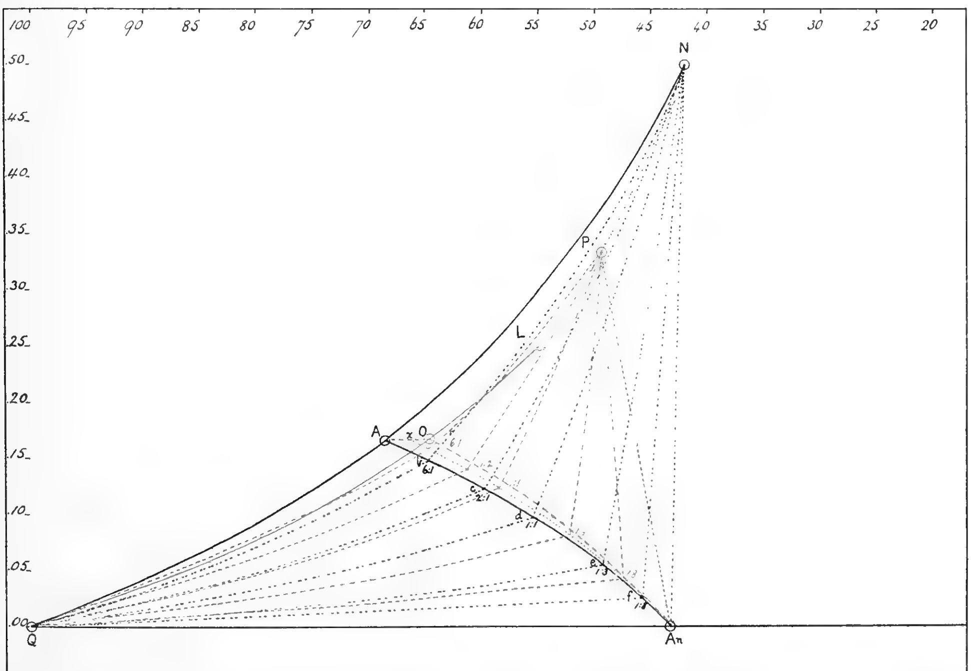


Diagram 3

such as phosphorus, titanium, zirconium, sulphur, chlorine, fluorine, boron, etc., and their influence in modifying the proportions of the preponderant minerals is self-evident.

The discussion has been far from complete, but it is hoped that it may lead to a better understanding of the relations between the chemical and mineral composition of igneous rocks, especially the factors controlling the range of quartz on the one hand and of leucite and nephelite on the other. It certainly makes more evident the interdependence of the various minerals on one another and on the chemical composition of the magma. And it may possibly suggest lines of investigation that may contribute more substantially to our knowledge and conception of these intricate relationships. JOSEPH P. IDDINGS.

THE WEATHERED ZONE (YARMOUTH) BETWEEN THE ILLINOIAN AND KANSAN TILL SHEETS.[1]

PRELIMINARY STATEMENT.

THE full extent of the overlap of the Illinoian upon the Kansan has not been determined. It is certain that a sheet of Kansan drift underlies the Illinoian throughout its extent in southeastern Iowa, and in all probability it continues some distance eastward into western Illinois, in the section between Rock Island and Quincy.

There may be a sheet of Kansan age formed by the Illinois glacial lobe. The available data, however, do not place this beyond question. Occasional wells in central Illinois are reported to have passed through a black soil at some distance below the Illinoian till. But, so far as the writer is aware, no exposures of such a soil have ever been discovered. Professor Salisbury has collected data in southeastern Illinois and southwestern Indiana which support the view that there may be two distinct drift sheets in that region. It is his opinion that the upper or Illinoian sheet extends farther south than the lower sheet.[2] Whether the lower sheet is of Kansan age is still a matter for conjecture. It also is still an open question whether the drift of the east border of the driftless area in northwestern Illinois and southwestern Wisconsin is of Illinoian age or of earlier date. In view of these uncertainties this discussion of the Yarmouth weathered zone is restricted to the region where the Illinoian sheet of the Illinois lobe overlaps the Kansan sheet of an ice lobe lying farther west.

Numerous exposures of a soil and weathered zone have been observed at the junction of the Illinoian and the Kansan till sheets in the region of overlap between Davenport, Iowa, and

[1] Read before the Iowa Academy of Sciences, December 1897.

[2] Communicated to the writer.

Quincy, Illinois. The presence of this soil horizon was first brought to the writer's notice by a well section at Yarmouth in Des Moines county, Iowa. For this reason, and because the name of this village is less likely to be confusing than names which are more common, it seems appropriate to apply the name Yarmouth to this weathered zone. There is also at Yarmouth not only a soil horizon, but apparently a pronounced erosion between the Illinoian and Kansan sheets.

THE YARMOUTH SECTIONS.

About ten years ago, Mr. William Stelter, of Yarmouth, Iowa, sunk a well near that village which passed through a bed of peat at the base of the Illinoian till sheet. The peat contained small bones which have been identified by Dr. F. W. True, of the United States National Museum, as (1) a portion of the pelvis and upper part of the femur of the wood rabbit (*Lepus sylvaticus*), and (2) the scapula of the common skunk (*Mephiticus mephitica*). The following section is based upon a statement made by Mr. Stelter soon after the well was dug and upon specimens of the several classes of material penetrated, which were also furnished me for examination :

	Feet.
Soil and loess loam,	4
Yellow till (Illinoian),	20
Gray till (Illinoian),	10
Peat bed with twigs and bones,	15
Gray or ashy clay containing fragments of wood,	12
Fine sand,	16
Yellow sandy clay with few pebbles (Kansan),	33
Total depth,	110

One mile south of Yarmouth, on the farm of Mr. F. Smith, a well was in process of excavation during a visit made by the writer to that region some years later, and the following section was determined by examination of the material in the dump, and with explanations by the well-borer. The well is located on a high point on the ridge marking the border of the Illinoian drift, perhaps 25 feet higher than the village of Yarmouth, which also stands on the ridge. It will be observed that the black muck penetrated in this well is at a level fully 40 feet lower than in the well at Mr. Stelters. This difference in level is interpreted to be due to one well having struck into a valley cut into the Kansan drift, while the other well entered the Kansan drift near the level of the bordering uplands.

SECTION OF WELL AT F. SMITH'S, NEAR YARMOUTH.

	Feet.
Yellow till (Illinoian), - - - - - - - -	36
Sand with thin beds of blue clay and also of cemented gravel, - - - - - - - - - -	73
Black muck containing wood, - - - - - -	6
Sand and gravel, probably alluvial, - - - -	8
Gray silt nearly pebbleless, apparently alluvial, - -	15
Blue till (Kansan), - - - - - - - -	42
Total depth, - - - - - - -	180

If my interpretation of the records at Yarmouth is correct, there is here not only a notable accumulation of peat and muck between the Kansan and Illinoian, but also an erosion of the Kansan till sheet to a depth of 40 feet prior to the deposition of the Illinoian. Since these sections are based entirely upon well records, they afford a less clear idea of the relation of the beds than might be afforded by valley excavation.

Exposures in neighboring districts.—One of the most satisfactory exposures yet found is that afforded by a ravine about one mile northeast of West Point, in Lee county. This was first seen by the writer in 1894. The following section may be obtained by descending the gully at the roadside:

	Feet.
Surface silt (loess), - - - - - - - -	6
Black soil with ashy gray subsoil, - - - - -	5
Brown till containing many bowlders, among which were two red jaspery conglomerates (Illinoian), - -	15
Black mucky soil with gray subsoil (Yarmouth), -	6
Brown clay with few pebbles (Kansan), - - - -	15
Total, - - - - - - - -	47

This exposure was visited by Professor T. C. Chamberlin and Dr. H. F. Bain in August 1896 and by each the black material beneath the till was considered a typical soil, and the gray material below a typical subsoil. The slightly pebbly brown clay beneath this subsoil shows no response with acid. Other exposures, however, have been found in which a response with acid may be obtained within six feet below the base of the lower or Yarmouth soil.

Between West Point and Denmark, a distance of seven miles, records of thirteen wells have been obtained in which a soil was found between the Illinoian and Kansan till sheets. The thickness of the soil ranges from 2 to 5 feet and its depth below the surface ranges from 16 to 45 feet; the usual distance to the soil is about 30 feet. This represents, therefore, the combined thickness of the Iowan loess and Illinoian till sheet. The loess, however, has a depth of but 5 to 10 feet. Of several wells made at Denmark in 1894 to 1897 the writer has witnessed the excavation, and finds that the leaching beneath the lower soil extends about 6 feet into the Kansan till sheet. One of the most satisfactory sections near Denmark is the following, made on the farm of Mrs. Van Tuyl:

	Feet.
Surface silt or loess of yellow color slightly calcareous and containing a few small pebbles near base,	7
Brownish yellow till, slightly calcareous and with few pebbles (Illinoian),	10
Brownish yellow till very pebbly and calcareous (Illinoian),	8
Blue clay with few pebbles (Illinoian),	10
Black mucky soil with wood (Yarmouth),	2
Brownish yellow till (Kansan),	12
Hard blue till (Kansan),	6
Limestone,	4
Total	59

In this connection it may be remarked that several of the wells in the vicinity of Denmark pass through 25 or 30 feet of oxidized Kansan till and enter rock without striking a blue till, but exposures in ravines both north and south of the villages show a dark blue-black till thickly set with fragments of wood. This occurs at a level lower than the rock surface at Denmark and has a striking similarity to exposures in other parts of the state which are suspected to be pre-Kansan in age.

Exposures at Davenport, Iowa.—The Illinoian till sheet as above noted is known to overlap the Kansan as far north as Davenport, Iowa. There are excellent exposures of both sheets within the limits of that city and also at points a few miles west near Blue Grass. An exposure in Davenport on Eighth st. between Myrtle and Vine was discovered by Professor J. A. Udden and has been visited by Professor Calvin, Mr. Bain, and the writer, each of whom recognizes the presence of both sheets of drift and also the Yarmouth weathered zone. The surface of the Kansan till sheet has the appearance of slight erosion, for it shows a rise of about 15 feet in a distance of 20 or 30 rods. The Illinoian till sheet rests unconformably upon the eroded Kansan, reaching a lower level at the south end of the exposure than at the north. In making the descent along Eighth st. the following series of beds was found:

	Feet.
Loess, - - - - - - - - - - -	30
Weathered zone of reddish brown till (Sangamon), - -	3
Unleached brown till (Illinoian), - - - - - -	15
Weathered zone of gummy gray clay (Yarmouth), - -	3
Brown till changing to gray color, 12 to 15 feet (Kansan),	30

Exposures in Adams county, Illinois.—The most southerly exposures of the Yarmouth weathered zone yet observed are in Adams county, Illinois. In a ravine near Woodville in the northern part of the county two sheets of brown till appear which are separated by a gray gummy clay. This clay is thoroughly leached, while the till immediately above it is unleached. The latter has a thickness of only 10 or 12 feet. Another exposure was found at a well in process of excavation on a farm eight miles east of Quincy. This section is similar to that in the ravine except that the Illinoian till sheet has a thickness of 20 feet. Another exposure was found north of Payson near the base of a ridge of Illinoian drift. The gray clay here rests upon a gravelly bed instead of a sheet of till, but appears to be of similar origin and age to the other beds referred to the Yarmouth stage.

Within a few miles south from this exposure the border of the Kansan drift emerges from the edge of the Illinoian and passes southward into Missouri. The driftless peninsula found by Professor Salisbury here sets in and occupies a narrow strip west of the Illinois from Pike county to the mouth of that stream,[1] beyond which the margins of the Illinoian and Kansan sheets take widely divergent courses. Fortunately there was sufficient overlap north from this driftless peninsula to make clear the interpretation that the Illinoian is a markedly younger sheet than the Kansan. This difference in age was suspected to occur from a comparison of maturity of valleys in the two districts, but the testimony of the weathered zone preserved below the Illinoian was necessary to confirm it.

FRANK LEVERETT

DENMARK, IOWA.

[1] See Proc. A. A. A. S., Washington meeting, 1891, pp. 251–253.

THE PEORIAN SOIL AND WEATHERED ZONE (TORONTO FORMATION ?)[1]

THE interval between the Iowan and Wisconsin stage of glaciation has been provisionally named Toronto by Professor Chamberlin, because of excellent exposures of interglacial fossiliferous beds along the Don Valley in Toronto, Ontario, which may prove to have this age.[2] Professor Chamberlin remarks in connection with the introduction of this name that the grounds for this correlation are not very strong, and further investigation may show them to be erroneous, but that it is not likely that the beds upon the Don can be referred to any earlier period. He further remarks, that, "Whether the beds on the Don belong to the horizon suggested or not, it is certain that vegetal beds were formed in the interval of the retreat between the formation of the Iowan till and the formation of the Wisconsin till, and some of these less well developed and less known deposits must be looked to as a type of this interglacial horizon if the Toronto beds prove unavailable."

In view of the uncertainty attached to this correlation, it seems advisable to employ for the present a substitutional name which is known to be applicable to the interval between the Iowan and the early Wisconsin. In case the correlation suggested by Professor Chamberlin is demonstrated to be correct the name Toronto has precedence.

Extensive deposits of muck and peat occur at the base of the Wisconsin drift in northern Illinois, notably in McHenry, Kane, De Kalb, La Salle, and Bureau counties, which are in all probability immediately underlain, in some cases at least, by

[1] This paper forms part of an unpublished report by the writer on the Illinois glacial lobe. It is published in connection with the two papers read before the Iowa Academy because of the close relation of the subject-matter.

[2] Classification of American Glacial Deposits, by T. C. CHAMBERLIN, JOUR. GEOL., Vol. III, 1895, pp. 270–277.

Iowan drift. In central and western Illinois the soil is in places underlain by a fossiliferous silt, referred with some confidence to the Iowan loess. In eastern Illinois the Iowan till may be present. This soil horizon, together with lower soil horizons, was discussed by the writer in a paper presented at the Cleveland meeting of the American Association for the Advancement of Science.[1] At that time the separation of the Iowan sheet from the Illinoian had not been made and all the soils were referred to a single horizon. The later developments have led the writer to separate the soils found at, or slightly below, the Wisconsin drift into two classes—one class being thrown into the Sangamon stage, while the other is thrown into the stage under discussion. It is not possible in all cases to decide to which class a buried soil should be referred, for in some cases its existence is known only through well records. The separations thus made are set forth in detail in a report by the writer yet unpublished.

In selecting a name for the horizon, the ideal locality would be one in which the earliest sheet of Wisconsin till overlies the Iowan till. In the vicinity of Marengo, in McHenry county, a black muck has been found at the base of the Wisconsin drift, and it apparently rests on Iowan till. This might be taken as a type locality were it not that the Wisconsin drift at that point may not include the Shelbyville or earliest Wisconsin sheet of till. The same objection may be urged against buried soils found in Kane, De Kalb, La Salle, and Bureau counties, for in all these counties the outer Wisconsin ridge appears to be the Bloomington moraine, and the limits of the Shelbyville may be to the east of this ridge. It has seemed advisable, therefore, in the selection of a type locality to pass to central Illinois, where the Shelbyville sheet extends beyond the later sheets of Wisconsin drift. This, unfortunately, carries us beyond the Iowan till, but the loess, whose deposition seems to mark the close of the Iowan glaciation is there well developed. The interval between the loess and Shelbyville till sheet probably marks as

[1] For abstract of paper see Proc. A. A. A. S., 57th meeting, 1888, pp. 183–184.

well the time between the culmination of the Iowan and Wisconsin glaciations as if taken where the Shelbyville sheet overlies Iowan till.

The loess has been traced back in valley exposures several miles beneath the Shelbyville till sheet in northern Tazewell county, Illinois, and beneath the combined Shelbyville and Bloomington sheets in Woodford and Bureau counties. Farther south it has been recognized in well sections in southern Tazewell, northeastern Logan, western De Witt, southern Macon, and western Sullivan counties, Illinois. The phase of loess known as white clay has been traced several miles up the Kaskaskia and Embarras valleys in Shelby and Coles counties beneath the Shelbyville till sheet.

Of the several exposures those east of Peoria in northern Tazewell county are the best displayed. Decisive evidence is also found at these exposures of an interval of some length between the deposition of the loess and the deposition of the overlying Shelbyville till sheet. In view of these conditions in the vicinity of the city of Peoria it has seemed appropriate to apply the name Peorian to the interval between the Iowan loess and the Shelbyville till sheet, a till sheet which appears to be the earliest of the Wisconsin series.

In exposures along the T. P. & W. R. R., east of Peoria, and also on the east bluff of the Illinois opposite that city, the Shelbyville sheet is underlain by a bed of fossiliferous loess, similar to that found on the surface of the Illinoian outside the limits of the Shelbyville drift sheet, both in texture and in age. The loess is 8 to 12 feet in thickness, or about the same as on the uplands outside the Shelbyville sheet. It occurs at a corresponding elevation of about 200 feet above the Illinois River. Beneath it there is exposed fully 100 feet of the older drift sheet.

The upper part of the loess to a depth of two or three feet presents a reddish brown color, and is thoroughly leached. The leaching extends usually to a depth of about six feet. But beneath that depth the loess is often calcareous. The Shelbyville till was found to be very calcareous immediately above the loess. The evidence of a weathered zone at the top of the loess is as clearly shown as at the top of the underlying Illinoian till and several exposures occur in which the two weathered zones may seem in vertical sections. It is probable, however, that such a zone would be developed more rapidly in the loess than in the till, because of the greater porosity of the former.

Evidence of an interval between the Iowan and early Wisconsin glaciations is found in the great dissimilarity in the outline of the two ice sheets. The outline is more out of harmony, both with the early Wisconsin and the Illinois, than the outline of those sheets with each other. The great extension toward the south border of the driftless area, both in the Iowa and Illinois lobes of Iowan ice is singularly out of harmony with both succeeding and preceding glaciations. The shifting of lobes involved in the change from the Iowan to the early Wisconsin can scarcely be assumed to have occurred in a brief interval. The moraine-forming habit of the Wisconsin and absence of distinct morainic belts in the Iowan also implies a change in glacial conditions that can scarcely be assumed to have taken place suddenly.

Evidence of an interval between the deposition of the Iowan loess and associated silts, and that of the Shelbyville till, is found in a change in the attitude of the land which resulted in a marked deepening of the valleys. There appears to have been a greater depth of excavation during the Peorian interglacial stage than during the Sangamon. The breadth of excavation, however, was reduced to but a fraction of that in the Sangamon stage. The amount of change in altitude can as yet scarcely be even conjectured, much less demonstrated, but its effects on the drainage are such as to support the view that it denotes a time interval of considerable length; a view which is also supported by the work accomplished in deepening the valleys. Comparing the work with substages of the Wisconsin it appears that the interval may not greatly exceed that between the Shelbyville and Bloomington ice advances. The Shelbyville sheet had apparently become channeled by streams prior to the Bloomington substage of glaciation to nearly as marked a degree as the channeling below the level of the loess effected in the Peorian stage of deglaciation. There is also a marked increase in the stream gradient, the Bloomington drift sheet being accompanied by a much more vigorous gravel outwash than that which accompanies the Shelbyville sheet. In the writer's opinion it is questionable if the interval between the Iowan and early Wisconsin invasions covers more than a comparatively small part of the time occupied by the intervals between the Iowan and Illinoian, and between the Illinoian and Kansan. The union of the several lines of evidence just cited would seem to support the view that it is longer than interglacial substages of the Wisconsin. The view of a brief interval between the Iowan and Wisconsin meets a strong objection, however, in the supposed attendant deposits at Toronto.

Turning to the Toronto formation it is found that a fossiliferous silt occupying a horizon between bowldery glacial clays has a fauna and flora which denote a climate fully as mild as at present characterizes that region.[1] In discussing this formation Dr. A. P. Coleman remarks that unless the Labrador gathering ground is shown to have stood much higher than at present it can scarcely be supposed that a widespread sheet of ice was maintained there, while oaks and maples and pawpaws flourished on the land and Mississippi unios in the waters within 400 to 500 miles to the southwest. In the absence of any evidence of such an uplift he concludes that the ice fields were completely melted during this interglacial epoch. Professor D. P. Penhallow remarks that the arborescent forms of vegetation in these interglacial beds are of species such as may now be found in the same region.

[1] See descriptions by DR. A. P. COLEMAN and PROFESSOR D. P. PENHALLOW in American Geologist, Vol. XIII, Feb. 1894, pp. 85–95. See also additional interpretation by DR. COLEMAN, in JOUR. GEOL., Vol. III, pp. 274, 622–645.

For description of fossiliferous beds at Scarborough Heights and other localities near Toronto, by DR. G. J. HINDE, see Journal of the Canadian Institute, April 1877.

The extent of deglaciation suggested by these beds, so far as space is concerned, can scarcely be supposed to have been exceeded either by the Sangamon or the Yarmouth stage of deglaciation. The Toronto beds constitute probably the most decisive evidence yet brought forward in support of an extensive deglaciation within the glacial period. The time involved may reasonably be supposed to involve a portion of the glacial period by no means small. Its rank should be as high as that of any of the interglacial stages, even if less prolonged than some of the earlier stages of deglaciation. Should it be proved to represent the interval between the Iowan and Wisconsin deposits, as now seems probable, the evidences above cited, from the peripheral portion, may aid in determining its length, namely, the leaching and erosion of the Peorian stage. As yet the fauna and flora buried beneath the peripheral portion of the Wisconsin drift have received little or no attention. Possibly by the aid of this line of study the question of correlation may be settled.

FRANK LEVERETT.

A GEOLOGICAL SECTION ACROSS SOUTHERN INDIANA, FROM HANOVER TO VINCENNES.

INTRODUCTION.

During the field season of 1896 the Indiana University Geological Survey undertook to map, geologically and topographically, a section across southern Indiana, reaching from the Ohio River at Hanover on the east, to the Wabash River at Vincennes on the west. The strip of country mapped is 6 miles wide, 120 miles long, and is embraced in the row of townships numbered 3 north.

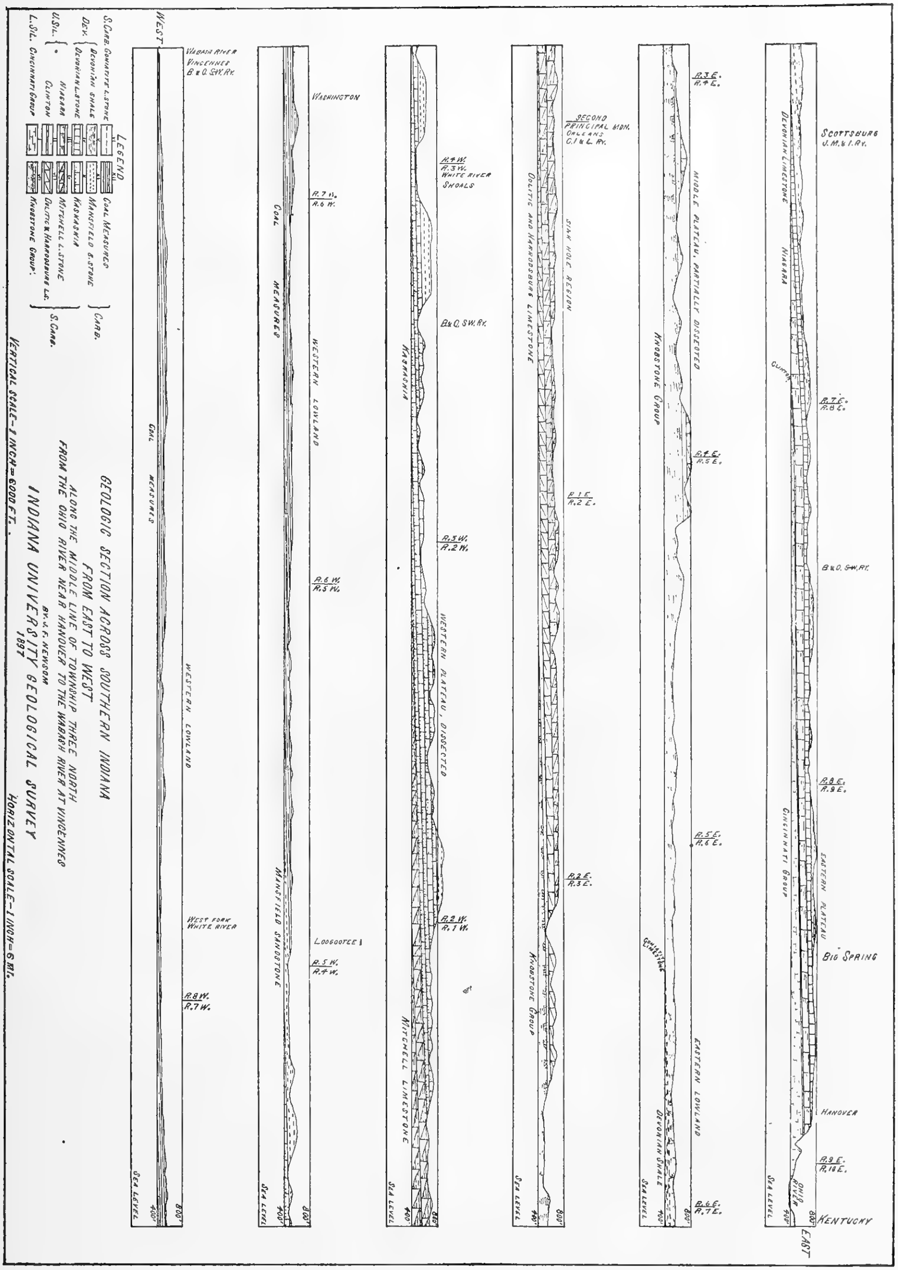
METHOD OF RUNNING THE SECTION.

The topographic work was done by means of aneroid barometers, with a line of levels through the territory by which the aneroid readings were checked. This line was run as far as Willow Valley station in Martin county, and as near the middle of the strip of country to be mapped as the conditions would permit; the elevations were obtained by means of the vertical arc, and are as accurate as the necessities of ordinary topography and geological cross sections demand. The line of levels was checked on the J. M. & I. and the B. & O. S.-W. R. R., where these roads were crossed. The dips of strata as shown by these levels may be depended upon within the suggested limits.

The section chosen was selected because the geological horizons and the topography crossed by it are typical of almost the entire southern part of the state. The geological horizons cannot be taken up here in detail, but it is desired to point out some of the relations existing between the topography and the geology.

THE HORIZONS CROSSED AND THE RESULTING TOPOGRAPHY.

The eastern plateau.—Beginning in the east near Hanover, at the west side of township 3 north 10 east, the lowest rocks


GEOLOGIC SECTION ACROSS SOUTHERN INDIANA
FROM EAST TO WEST
ALONG THE MIDDLE LINE OF TOWNSHIP THREE NORTH
FROM THE OHIO RIVER NEAR HANOVER TO THE WABASH RIVER AT VINCENNES
BY J. F. NEWSOM
1897
INDIANA UNIVERSITY GEOLOGICAL SURVEY
VERTICAL SCALE—1 INCH=6000 FT.
HORIZONTAL SCALE—1 INCH=6 MI.
LEGEND
COAL MEASURES
MANSFIELD S. STONE
KASKASKIA
MITCHELL L. STONE
OOLITIC & HARRODSBURG L.S.
KNOBSTONE GROUP
CARB.
S. CARB.
S. CARB. GONIATITE L. STONE
DEV. DEVONIAN SHALE
DEVONIAN L. STONE
U. SIL. NIAGARA
CLINTON
L. SIL. CINCINNATI GROUP
WEST
EAST
WABASH RIVER
VINCENNES
B & O. S.W. RY.
WASHINGTON
WESTERN LOWLAND
WEST FORK WHITE RIVER
COAL MEASURES
MANSFIELD SANDSTONE
LOOGOOTEE
WHITE RIVER SHOALS
B & O. S.W. RY.
KASKASKIA
WESTERN PLATEAU, DISSECTED
MITCHELL LIMESTONE
SECOND PRINCIPAL MDN.
ORLEANS
C.I. & L. RY.
OOLITIC AND HARRODSBURG LIMESTONE
SINK HOLE REGION
KNOBSTONE GROUP
MIDDLE PLATEAU, PARTIALLY DISSECTED
EASTERN LOWLAND
DEVONIAN SHALE
SCOTTSBURG
J.M. & I. RY.
DEVONIAN LIMESTONE
NIAGARA
CLINTON
CINCINNATI GROUP
EASTERN PLATEAU
BIG SPRING
HANOVER
OHIO RIVER
KENTUCKY
SEA LEVEL
400'
800'

exposed in Indiana are the limestones and calcareous shales of the Cincinnati group. Near Hanover these beds have an exposed thickness of about 250 feet, reaching from near the tops of the bluffs along the Ohio River down to and below the level of that stream, which at this place is about 400 feet above mean tide. Overlying this series of soft strata are hard limestones belonging to the Clinton, Niagara, and Devonian (Corniferous). The combined thickness of these beds is about 180 feet.

The limestones resist the action of the weather, and owing to these hard, resisting strata above, and the soft, easily eroded strata below, the conditions are favorable to the formation of bluffs and waterfalls. So it happens that each short stream that flows eastward into the Ohio has the upper end of its gorge marked by a precipice or waterfall, varying in height from 40 to 90 feet.

When the top of the limestone is reached the country immediately becomes approximately level. The Devonian limestone is overlain by the Devonian black shale, and as this shale has no hard beds immediately overlying it, it does not produce a rugged topography. The dip of the Devonian limestone from Big Spring, township 3 north 9 east, section 16 to section 20, 3 north 8 east is 231 feet, or a little over 33 feet to the mile. This dip is not constant, but varies from 20 to 46 feet per mile, and is in every respect sufficient to cause the westward flow of the streams.

In the eastern edge of Scott county the westward dip of the Devonian limestone and the overlying Devonian black shale is probably at its minimum; the hills of this locality, and the exposures of limestone in the valleys, are probably due to this structural feature. While the hills are not high—ranging from 50 to 100 feet above the valleys—they nevertheless form the most marked topographic feature between the Ohio River and the Knobs.

The Devonian limestone finally passes beneath the drainage near the west line of township 8 east, the country immediately to the west becomes more gently rolling, and the low hills are made up of black shale covered over in most cases by glacial material.

The Devonian black shale outcrops over a strip of country some twelve miles wide. Except at its eastern edge where it has been eroded to a feather edge, and where the underlying limestone controls the topography, it forms very low hills, and often almost flat plains. The black shale passes beneath the drainage near Scottsburg. In a deep well drilled at Scottsburg its thickness was found to be 120 feet.

The eastern lowland.—Overlying the Devonian black shale is the Knobstone group of clay shales, sandy shales, and sandstones. The lower limit of this group is marked by the Rockford Goniatite limestone, which, owing to its thinness has but little effect on the topography. The lowest beds of the Knobstone group are made up of clay shales. These clay shales, with the underlying Devonian black shale, are directly responsible for the low country and very gentle topography to be found throughout southern Indiana, between the high escarpment known as the Knobs, and the deep gorge of the Ohio River. The western part of this region may be properly styled the eastern lowland.

One noticeable feature of the topography from the top of the escarpment near Hanover, where the elevation is 800 feet above tide, to Scottsburg (570 feet above tide), is the gradual westward slope of the country, corresponding almost exactly to the average dip of the strata. The tops of the low hills of this region are all found in approximately the same slightly westward dipping plain.

The "Knobs" and the middle plateau.—The Knobs form by far the most important topographic feature in the eastern part of the extreme southern portion of Indiana. They are made up of Carboniferous strata belonging to the "Knobstone group" with its capping Carboniferous limestones. The Knobs do not form a range of hills, properly speaking, but are rather a high escarpment, generally facing eastward, with a plateau sloping very gently to the west, and with outliers to the east. The geological conditions, so far as they bear upon topography, are very similar to those along the Ohio River, to the east, *i. e.*, a thick series of soft and unresisting strata is capped by sandstone and more resisting limestones, thus making possible bold hills and steep slopes.

The parting between the Knobstone and the overlying limestone is not a sharp one, but is made up of interstratified limy and sandy layers, indicating a gradual change in the conditions of sedimentation. The easternmost point in the line of parting between the Knobstone group and the overlying limestone is at the southeast corner of section 18, 3 north 5 east. Passing on westward the top of the Knobstone is found lower and lower in the hills, until it finally passes beneath the drainage in the northeast quarter of section 19, 3 north 3 east, at an elevation of 537 feet, or 342 feet lower than its outcrop, just eleven and one-half miles east. This shows a general westward dip averaging about twenty-six feet per mile.

The sink hole region.—Overlying the Knobstone group, and still dipping to the west are the Harrodsburg and Mitchell limestones (of Hopkins and Siebenthal), and the Kaskaskia group, all belonging to the Lower Carboniferous. In the region of its easternmost exposure the limestone is very thin, being eroded to a feather edge. Passing westward from its easternmost exposure, it is found lower and lower in the hills, because of its westward dip, and the country becomes accordingly less rugged and takes on the gently rolling and pitted sink hole character common in limestone regions.

In this region and on westward across the outcropping Mitchell limestones, and until the Kaskaskia beds are reached, the country has a very gentle westward slope. This is less, however, than is to be found east of the "Knobs," and it is also less than the dip of the rocks; this is due to the fact that the limestones do not weather so easily as do the shales.

There is a noticeable increase in the size of the sink holes in going across the limestone region from east to west. The sink holes at the eastern edge are rarely more than 20 feet deep and 200 yards across, while in the western part they are sometimes miles in length and from 50 to 200 feet deep, forming valleys, similar in every respect to ordinary valleys of erosion, except that they have no surface outlets for their drainage. The increase in the size of the sink holes is, of course, due to the greater thickness of the underlying limestone.

The western edge of the Mitchell limestone is found just west of the second principal meridian, where, overlying it, is the lower Kaskaskia limestone, a hard, close-grained, resisting bed, which is in turn overlain by a series of limestones and sandstones. The effect of these beds upon the topography is quite noticeable. The hills rise higher and higher to the west, until on the western edge of Lawrence county, where they are capped by the highest beds of the Kaskaskia group, they are from 100 to 250 feet above the valleys. Many of these valleys are only large sink holes, and have no surface outlets.

The Mansfield sandstone, or western plateau.— Overlying the Kaskaskia beds is the Millstone grit (Mansfield sandstone of Hopkins) or the sandstone that forms the lowest member of the Upper Carboniferous. This sandstone controls the topography in the region in which it forms the surface rock, and is, in the main, responsible for the high hills of Martin county. It has a gentle westward dip and owing to this fact the highest hills of the region are found near its eastern limit. The hills decrease in height with the dip of the rocks to the west. The resulting topography is essentially that of a thoroughly dissected plateau.

The western lowland.—The Mansfield sandstone is finally lost to view at the western edge of Martin county, a short distance east of Loogootee. West of this point the country is level, or very gently rolling. There is here an abrupt transition from the rugged hills capped with sandstone, in Martin county to the much lower, level country underlain by coal-bearing shales and sandstones at the east side of Washington county.

Overlying the Mansfield sandstone, and extending from its upper limit to the west line of the state, the country is underlain by the coal-bearing shales and sandstones of the Upper Carboniferous. These beds are easily attacked by eroding agencies, and have, therefore, already been worn down very near to their base level of erosion (if, indeed, they have ever been high above that level), leaving a comparatively level flat country. This region is covered with more or less glacial material.

The accompanying profile section shows clearly these different topographic features, and also the relations between the topography and the underlying strata.

CONCLUSION.

In conclusion, attention should be called to the following points:

a. In passing from east to west across southern Indiana, three prominent topographic features are crossed, and these features are the results of combinations of strata as follows: (1) the high eastward escarpment along the Ohio River caused by a thick series of easily eroded calcareous shales overlain by thick and resisting limestones; (2) the high eastward-facing escarpment with its outliers to the east, known as the "Knobs." This escarpment is the result of a thick series of soft clay and sandy shales, protected by sandstones and resisting limestones. Along the line under discussion this escarpment is twenty-eight miles west of the escarpment along the Ohio; (3) the high hills of Martin county, which are the result of a series of limestones and sandstones capped by more resisting sandstones and which do not rise as an escarpment from the east, but become gradually higher, owing to the resisting nature of their lowest beds. The distance from the Knobstone escarpment to the highest hills capped with the Mansfield sandstone is about thirty miles.

b. The structure of each of these topographic features where crossed by the section is essentially the same in different stages of development, *i. e.*, that of a dissected plateau, sloping gently to the west. In the eastern, or the Devonian limestone plateau, in the region of Ohio, dissection has scarcely begun, as none except the streams flowing directly into the Ohio have deep gorges, and these are only from one-half to one and a half miles long; in the middle, or Knobstone plateau, dissection has progressed much further than in the eastern one; while the western or Mansfield sandstone plateau has been completely dissected by its streams.

It is possible that this peculiarity in the amount of erosion that has taken place in these different plateaus is the result of the character and former upward extension of the overlying formations in each case.

c. The top of the eastern plateau where crossed by the section is 800 feet above the sea, that of the middle is 820 feet, and that of the western 880 feet above tide, while but a short distance to the north or south the topographic sheets show the elevations of these plateaus to correspond even more closely.

These closely corresponding elevations point strongly to the conclusion that the present topography of southern Indiana has developed from an old base level; a former plain of deposition, or a combination of the two, might, however, have given rise to the present conditions.

JOHN F. NEWSOM.

INDIANA UNIVERSITY,
Bloomington, Indiana.

NOTES ON THE OHIO VALLEY IN SOUTHERN INDIANA.

INTRODUCTION.

In recent years much work has been done on the streams and abandoned stream channels leading through or from glacial regions. The upper Mississippi, the Illinois, the lower Missouri, many smaller streams in Minnesota, Wisconsin, Illinois, and Iowa, the Wabash, and the upper Ohio have been examined more or less carefully, but on the lower Ohio, and more particularly that part between the falls at Louisville and the mouth of the Wabash, little or nothing has been done.[1]

The present paper deals with a portion of this unexamined region in Spencer county, Indiana. Spencer county is in the southwestern part of Indiana. With reference to the Ohio, it is about 130 miles below the falls at Louisville and 95 miles above the mouth of the Wabash.[2] The region is particularly interesting, because it is near the middle of the base of the unglaciated triangle of Indiana.

The following paper will discuss (1) an old cut-off of the Ohio, (2) a series of river sands and gravels which seem to be Tertiary, (3) a probable extension of the Lafayette sea up the Ohio valley, (4) peculiarities of the loess on the bordering hills, including an apparent twofold character of the loess, and (5) a record of continental oscillation furnished by the deposits at this point.

The three physiographic regions.— Physiographically, Spencer county may be divided into two parts, a plain and a hill region. The plain may be subdivided into three parts. First, a broad,

[1] Jour. Geol., Vol. III, "Preglacial Valleys of the Mississippi," by Frank G. Leverett, pp. 745 and 759.

[2] For general location see Figs. 1 and 2. Enterprise is in the western part of the region described.

level plain extends southwest along the western boundary of the county. It has the same general trend as Little Pigeon Creek, and will therefore be called Pigeon Plain, although this valley is not now occupied by Little Pigeon Creek.[1]

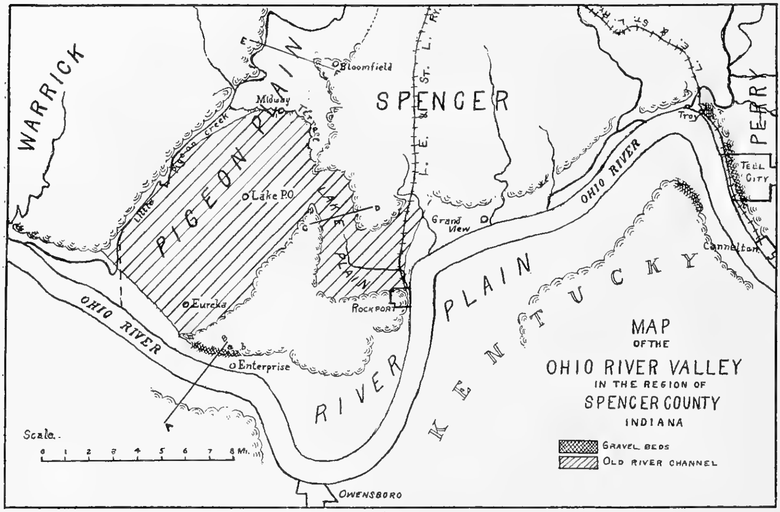


Fig. 1

Pigeon Plain is naturally divided into two portions by a terrace about fifteen feet high, which begins near the point where Lake Plain joins it, and extends in a general northwesterly direction past Midway to Little Pigeon Creek (Fig. 1). The plain north of this line is about fifteen feet higher than the portion south. The soil north is a reddish clay in part of the region and a very black peaty soil in the other; while the soil south is entirely different, being the same as that which makes the river bottoms and the River Plain, into which it merges at its south end. Other differences between the northern and southern parts of Pigeon Plain will be mentioned later.

Where Pigeon Plain enters the northern part of the area under consideration it is about two miles wide. It gradually

[1] The separation of Pigeon Plain and the valley of Little Pigeon Creek is not shown.

widens until at Midway it is about four miles and at Lake P. O. five, at which width it continues until it enters the second division of the plain region, the River Plain of the present Ohio.

The average width of the River Plain is between four and

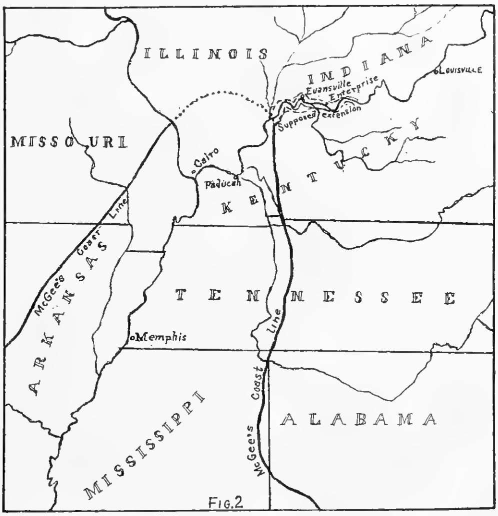


Fig. 2

MAP OF COAST LINE DURING THE LAFAYETTE ACCORDING TO MC.GEE, SHOWING ALSO SUPPOSED EXTENSION UP THE OHIO VALLEY

five miles. That portion which lies in Indiana is very irregular on account of the meandering course of the river. It includes all land locally termed the river bottoms. Three and a half miles below Enterprise, River Plain merges into Pigeon Plain.

The third portion of the plain enters, or rather leaves, the River Plain between Grandview and Rockport (Fig. 1), its southern portion including part of the town of Rockport. It is here three miles wide, but soon narrows down to two miles. It extends westward three miles, where it turns abruptly northward, and there narrows to about one mile. After going three miles in this direction it turns westward again, and enters Pigeon Plain two miles east of Lake P. O. The narrow part of this plain was occupied by a shallow pond of water when this country was first settled. This pond was called "The Lake" by the early settlers. For this reason this division may be termed Lake Plain, although the lake is a result and not a cause of the plain.

These three plains so merge into one another that it is impossible to tell where one begins and the other ends. The average level of the plain above low water in the Ohio at Rockport is about thirty-five feet. The difference in levels of all three is very slight, not being over twenty feet, except where trenched by modern channels. The surface is so nearly level that large portions of this county either are or were swampy.

The hill region occupies all land not occupied by the plains above outlined. It will be seen from the location and interconnection of these plains that the south part of the hill land is completely cut off from the north or main upland, and stands as a roughly triangular tract, with channels or low plains on every side.

This region is characterized by a great number of hills rising on an average from forty to sixty feet above the plain. The highest part of the triangular hill land is in Rockport, near the junction of Lake and River plains, where the hills rise 110 feet above the plain. The next highest is at the junction of Pigeon and River plains, where the hills reach the height of ninety feet; the bordering hills being in general higher than those in the interior and the hills on the south and east higher than those on the west.

The northern portion of the hill land is higher and more irregular. The highest point measured is about four miles north of Rockport, where one of the "Knobs" rises 240 feet above the general level of the plain, or 275 feet above the Ohio River at Rockport.

The loess.—The hills bordering the plains in the triangular hill land are all covered with loess. The southern border of the northern portion of the hill land is covered from Grandview as far as the point where Lake and Pigeon plains meet. From this point the loess follows the terrace mentioned above northwestward.

The region in the interior, in all the triangular hill land, and for a short distance north of the southern boundary of northern hill land is covered with typical interstream loess.

It follows in all of its details the characteristics of loess as given by Salisbury.[1] It is best developed along the hills bordering stream channels, where it has the peculiar yellow or yellowish buff loess color. Where exposed it weathers into perpendicular banks. As it recedes from the stream channels it becomes thinner and less characteristic. This change in thickness is accompanied by a change in color, so that in the interstream areas it so closely simulates residuary earth that it is impossible to tell where one begins and the other ends. In parts of the deposit, loess-kindchen are very numerous. They are of the same type as those described by Call in Arkansas,[2] which, according to his statement, differs from the typical northern loess-kindchen in being solid. Limonite tubes and concretions and immense numbers of very small land shells occur in some deposits.

The change from typical bluff loess to interstream loess is noticeable in passing northward from the terrace in Pigeon Plain. This peculiarity is of much assistance in working out the origin of the terrace.

The thickness of the loess along the border hills will average about 20 feet. The highest elevation of the loess above the plain is at Rockport, where it rises 110 feet. It was seen at places on the "Knobs" at heights of about 100 feet. In nearly all of the region it extends down to the level of the plains, and much of the plains is made of redeposited loess.

Along the eastern shores of Pigeon Plain this loess is interlaminated with a grayish sand in its lower portions. Along the edge of the hills, and parallel with them, are many lenticular sand hills ranging from 10 to 30 feet high.

[1] Ark. Geol. Survey, 1889, Vol. II, "On the Relationship of the Pleistocene to pre-Pleistocene formations of Cowley's Ridge," pp. 226–228.

[2] Ark. Geol. Survey, 1889, Vol. II, "Cowley's Ridge," by R. Ellsworth Call, p. 38.

The obstructed valleys.—All the valleys which come from the hill region into the plain along the line of hills on the western side of the triangular upland have a very abnormal character. At the points where the streams pass from the upland to the plain, two long ridges of loess and sand 20 to 40 feet high jut out from each side like the arms of a great dam. These two parts almost meet, and the stream passes through the narrow V-shaped space between them. These dams are continuous with the loess-capping of the hills, which is so regular here that it looks much like a great artificial embankment. Although these dams are best developed along this line of hills, a similar tendency to dam the mouths of valleys on the east and south sides of the triangular hill land is shown.

These peculiar loess dams must be taken into consideration in any theory accounting for the manner of deposition of the loess of this region. The fact that valleys have been found facing in all directions, seems opposed to a wind origin. A prevailing southwest wind blowing over dried mud flats in the River and Pigeon plains could have formed all the dams on the western side of the triangular upland, but could not have formed some of the others. For this reason it seems probable that the loess of this region was deposited on the bordering hills as a natural levee by the swollen waters of the river, and that the dams across the mouths of these valleys represent continuations of this levee.

Driven-well area.—In all the plain region bounded by these loess-capped hills, that is, all the River Plain, Lake Plain, and that portion of Pigeon Plain south of the terrace, excepting a very narrow strip in a few places along the base of the hills, wells reveal a great trench filled with an irregular series of clays and water-bearing sands and gravels. This is the region of the driven wells. In the hill region and most of the region in Pigeon Plain north of the terrace all wells strike rock at comparatively shallow depths.

At Rockport wells have been driven 70 feet in the river alluvium without reaching rock. The normal depth of wells in middle Lake Plain and northern Pigeon Plain south of the terrace ranges from 17 to 40 feet. Very few wells are deeper, and only those near the bordering hills reach rock. One well, 56 feet deep in the narrowest part of Lake Plain, did not reach rock. In River Plain wells range from 30 to 60 feet in depth.

From these wells can be learned something of the original depth of this filled valley. If all sands, clays, and gravels which underlie Lake, River, and a portion of Pigeon plains could be removed, a valley extending at least 56 and probably more than 70 feet below the present plain level, and having its sides of middle carboniferous strata, would be shown.

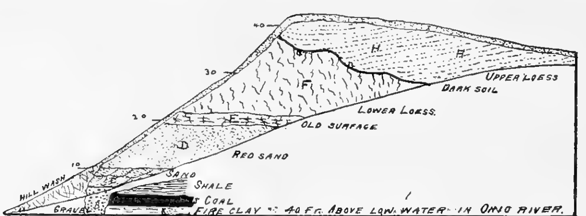
The old cut-off.—This valley under Lake Plain and the southern part of Pigeon Plain is the same depth as the half filled Ohio gorge of which it is a continuation. It is filled with the same materials. The hills on each side are capped with typical river-bluff loess in the same manner as those on the erosion scarp of the Ohio. The levels of the plain are so nearly the same that a portion of the waters in the flood of 1884 flowed swiftly through Lake Plain and entered Pigeon Plain, where one part followed the terrace and then turned southward and met the other part, which flowed south of Lake P. O., joining the waters of the Ohio again where Pigeon and River plains meet. This stream was four feet deep at the junction of Pigeon and Lake plains.

All these facts can lead to but one conclusion: The Ohio River at one time flowed through the Lake Plain and down through Pigeon Plain, entering the Ohio valley again between Enterprise and the eastern border of Warrick county.

To the erosive power of the river is to be attributed the greater part, if not the whole, of the gorge now occupied by that portion of the plain which has been called Lake Plain. In Pigeon Plain the work done was simply deepening and broadening on the eastern side of a broad valley extending from the northeast, which the river entered after cutting through the rock in Lake Plain. A portion of this more ancient valley, extending from the northeast, still remains intact north of the terrace, the terrace being simply the northern boundary of the Ohio's downcutting in the older valley. The conspicuous differences in width which exist between various parts of the cut-off are to be explained by the fact that the river entered an old river channel when it came to Pigeon Plain. Nearly all the swampy areas mentioned above are simply parts of the old channel which have been but imperfectly filled.

An ancient valley from the north.—The ancient stream plain which the Ohio entered after cutting through the hills two miles east of Lake P. O., is locally called Pigeon valley; but, as has been stated, it is not at present occupied by Little Pigeon Creek. A cross section of the country from *E* to *F*, Fig. 1, shows Little Pigeon Creek in a young, V-shaped, rock-bound valley, separated by a hill of sandstone 30 feet high from the broad old alluvial-filled valley east of it (Fig. 12). Another section running east and west half a mile north of Midway shows the same peculiarities. Well sections in a few places west and northwest of Midway show a depression of 60 feet deep, fielld with blue mud.

Tertiary gravel beds.—Near the base of the hills north of Enterprise (Fig. 1) is a series of sands and gravels. The roads cut through these bounding hills at different places and afford admirable sections of the formations. A section examined along the road running between sections 3 and 4, township 8, south range 7 west, showed the following strata (Fig. 3):[1]



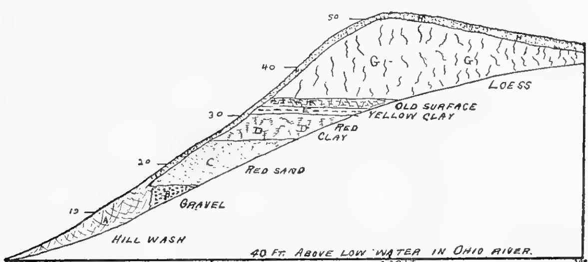
SECTION THROUGH BLUFF AT a, N.W. OF ENTERPRISE
Fig. 3

		Ft.	In.
A	Hill wash—a reddish sandy clay, - - - - -	5	0
B	Coarse gravel mixed with sand. The gravel is mostly a much glazed dark yellow chert, but also contains some		

[1] The location of this section is shown at *i* in Fig. 2.

	white quartz and fragments of geodes — largest pebbles from 3 to 4 inches in diameter. A layer of gravel about 3 inches thick stained black with manganese occurs near the base of the part exposed,	1	6
C	White, yellow and orange sands cross-bedded. In one place pure white sand is 9 inches thick. Three layers of white sand occur directly above the gravel. The line between the sand and the next stratum D is not well marked, the one grades into the other,	3	6
D	Brick red sand,	9	0
E	A much stained clay, indicating an old surface,	2	0
F	A brown loam below turning into a typical loess above full of loess-kindchen	10–15	0
G	A thin layer of dark soil discolored with iron, producing below plates of iron one-eighth of an inch,	0	3
H	Loess grading into surface humus,	5–10	0
I	Surface humus.		

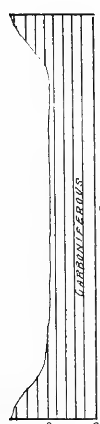
One mile east of the above the following strata were observed:



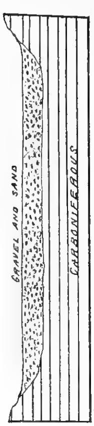
SECTION THROUGH BLUFF AT b, N.E. OF ENTERPRISE
FIG. 4

SECTION 2. (FIG. 4).

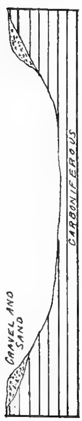
		Ft.
A	Hill wash — a reddish sandy clay,	10
B	Gravel — coarse, well-rounded yellow chert, with a few white quartz and geode pebbles somewhat stratified. Streaked with manganese, which in places forms a conglomerate,	5
C	Reddish sand turning above to reddish clay flecked with white,	10
D	Very red clay mottled with black,	5
E	Yellow to drab clay showing white streaks,	2



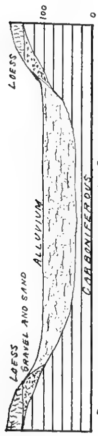
IDEAL SECTION FROM A TO B. FIG. 1, SHOWING VALLEY OF OHIO AT THE BEGINNING OF THE LAFAYETTE.
FIG. 5



IDEAL SECTION FROM A TO B FIG.1, SHOWING VALLEY OF THE OHIO AT CLOSE OF THE LAFAYETTE.
FIG. 6



IDEAL SECTION FROM A TO B FIG.1 SHOWING VALLEY OF OHIO AT THE CLOSE OF OZARKIAN UPLIFT
FIG.7



PARTIALLY IDEAL SECTION FROM A TO B FIG.1 SHOWING VALLEY OF OHIO AT THE PRESENT TIME
FIG.8

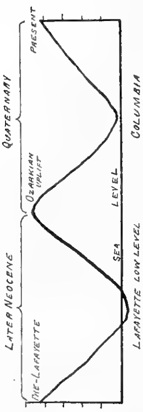
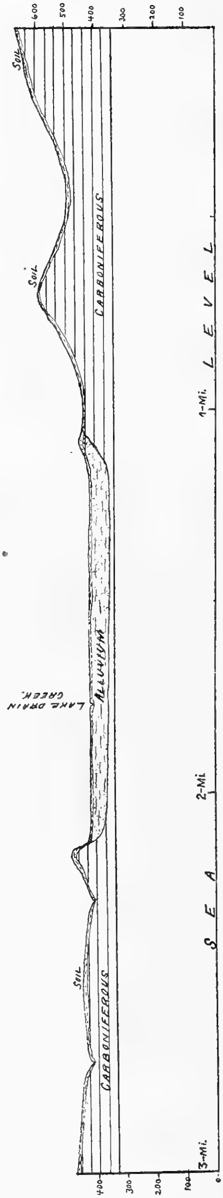


FIG.9
CONTINENTAL OSCILLATIONS OF OHIO VALLEY AT ENTERPRISE

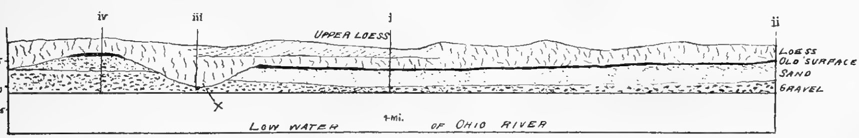


SECTION FROM C TO D FIG.1, SHOWING FILLING OF CHANNEL IN LAKE PLAIN
FIG.10

F	Mottled clay much weathered showing yellow, orange and black—evidently an old land surface,	3
G	Loess containing a few concretions,	15
H	Surface humus.	

One-half mile of section 1 (See *iii*, Fig. 11.) only a thin layer of gravel is found. At this place it is directly overlaid with loess full of concretions. The sands and clays which overlie it in the other sections are absent; but scarcely a quarter of a mile west on the same hill gravels and sands rise 35 feet above the plain (See *iv*, Fig. 11.) and about 70 feet above the river. The gravel here does not appear to be in any particular bed, although it is more abundant near the base of the hill. At times it is found in lenticular beds between the sands. Brick red sands were seen at a height of 35 feet. The pebbles in many places are cemented together, forming large masses of conglomerates. Through the sands are plates of iron as much as 3 inches thick. The old surface was visible but not very well defined.

One mile west of section 1, at *v*, Fig. 11, the following strata were observed:



IDEAL SECTION EAST AND WEST ALONG BLUFFS NORTH OF ENTERPRISE SHOWING UNCONFORMITY AND LOCATION OF SECTIONS DESCRIBED
FIG. 11

SECTION 5. (FIG. 11).

		Ft.
A	Gravel—same as that found in other section. Somewhat bleached,	20
B	Sandy clay, red flecked with white,	4
C	Brown to drab loess,	15
D	Typical loess,	15

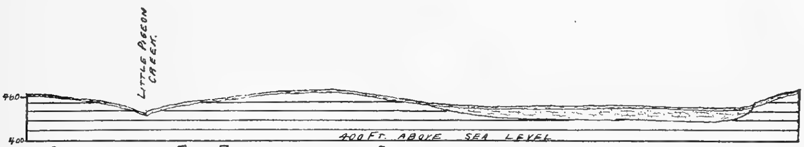
The bipartite character of the loess is clearly shown in section 1, and is also shown, though less clearly, in section 5. The widespread loess sheets of the southern Indiana and Illinois are considered by Leverett to belong to the Iowan age. This would seem to indicate that the lower loess is Illinoian and the upper Iowan.

By reference to Fig. 1 it will be seen that the sections given above approach very close to the extreme southwest corner of the triangular hill land. Gravel was observed to rise 18 feet above the plain in a hill west of section 5. One-half mile west of this point the hills turn northwest in Pigeon Plain. The height of the gravels in the bluffs northeast of Enterprise would indicate that they could be easily found if they existed in this line of hills trending northeast.

A very careful search, in all available places, failed to discover these gravels anywhere along the old river cut-off, and it seems certain that they do not exist there. If this is the case no considerable breach existed in the line of hills from the southwest corner of the triangular upland to Warrick county, at the time of the deposition of the gravel, else it would have been filled with gravel, and at least some fragment of the deposit would be left. This would seem to show the age of the cut-off; it was cut after the deposition of the gravel.

These gravels and sands have been referred to the later Tertiary for several reasons:

First: The composition of the gravel is such that it cannot be referred to the glacial period; no pebbles of undoubted northern origin being found in the beds. It is obvious that, on account of its nearness to the southern limit of the glaciers, no beds of gravels could have been deposited at this place either during or following the ice-invasion without containing glacial pebbles. The main component of the gravel beds is yellow chert, probably derived from the Lower Carboniferous formations, through which the Ohio passes. The fragments of geodes are doubtless mostly from the St. Louis limestone and Upper Knobstone groups of Indiana. The quartz pebbles must have come either from parts of geodes or the Carboniferous conglomerates or both. As the first ice invasion, in this part of the country, practically marks the beginning of the Pleistocene these gravel beds must be pre-Pleistocene. That the waters would have brought down glacial gravel, had these beds been deposited during any glacial or interglacial period, is shown by



SECTION FROM E. TO F FIG. 1, SHOWING PIGEON PLAIN AND VALLEY OF LITTLE PIGEON
FIG. 12

the fact that in a recent terrace between Rockport and Grandview several deposits of glacial gravel are found.

Second: The gravel and sand is unconformably overlain by loess (*x* Fig. 11.) In several places an old weathered surface is found between the loess and gravel. It seems probable that the lower loess is Illinoian. This is additional evidence pointing to the conclusion that the gravels are preglacial, for as has just been shown they cannot belong to any glacial or interglacial period.

Third: There is a marked lithological resemblance of these deposits to the lower members of the deposits of gravel in the Jackson Purchase Region of Kentucky. The Kentucky gravels were called "stratified drift" by Loughridge in his report on the Jackson Purchase Region,[1] and were referred to the Quaternary. The lower parts of this stratified drift have since been referred to the Lafayette division of the Neocene by McGee,[2] after two conferences of scientists in one of which Loughridge took part. The gravels also agree lithologically with the Lafayette sands and gravels in other parts of Kentucky as described by McGee.

Fourth: The nonoccurrence of preglacial gravels in Pigeon Plain is without a reasonable doubt and their absence and the presence of typical river-bluff loess along the sides of the valley

[1] Kentucky Geol. Sur. 1888, Jackson Purchase Region, p. 57.

[2] U. S. Geol. Sur., 12th Ann. Rep., 1890–1, p. 500.

point strongly to the conclusion that the cut-off was made between the time of deposition of those deposits; there must, therefore, have been a considerable time interval between the deposition of the gravels and the loess during which this valley was formed.

Fifth: Farther up the river[1] gravels are found on both the Indiana and Kentucky sides. Well sections at Rockport show that river alluvium extends over 70 feet below the level of the river plain. These two facts show that after the partial filling of the valley with gravel the land rose and the river trenched through the gravel and deep into the underlying Carboniferous rocks (Fig. 7). This gorge cutting is correlated with the main gorge cutting of the central part of this country caused by the Ozarkian or Post Lafayette uplift. Hence the gravels are pre-Ozarkian and if instead of taking the first glacial invasion to mark the beginning of the Pleistocene the Ozarkian uplift is taken, the gravels and accompanying deposits are still pre-Pleistocene.

There are these five reasons for believing the gravels and sands to be pre-Pleistocene. Briefly they are:

1. Absence of glacial pebbles in the deposit.

2. Unconformity and old soil between the gravel and the loess.

3. Lithological resemblance of beds to known Tertiary beds.

4. Erosion record furnished by old river channel (?).

5. Pre-Ozarkian deposition of gravel.

Since they are pre-Pleistocene they are here referred to the Lafayette divison of the Neocene because, so far as the writer is aware, they resemble no other pre-Pleistocene deposits.

Fig. 2 gives the location of the Lafayette coast line according to McGee.[2] From the Wabash River northward McGee represents the ocean waters as extending in an indefinite way over southern Illinois. Mr. McGee in speaking of this map says

[1] It is regetted that lack of time prevented the examination of the hills below Owensboro, Ky. For several reasons it is believed that a corresponding series of gravel will be found there.

[2] 12th Ann. Rep. U. S. Geol. Sur. 1890, pp, 353–521.

that the data from which it was made was incomplete in the Mississippi embayment and so the coast line is very general.

If these deposits are Lafayette it would seem that an arm of the sea extended up the Ohio valley from the great Mississippi embayment past Posey, Vanderburg, Warrick, Spencer and into, if not past, Perry county, Indiana. In order to fully establish the size and shape of this embayment it would be necessary to examine carefully all lands bordering the Ohio River on both sides from Perry county, Indiana, to the mouth of the Wabash. Figure 2 shows in a general way this supposed extension of the embayment.

The data collected throws some light on the history of the Ohio valley at this point. This history is shown in Figs. 5, 6, 7, and 8. In these no attempt has been made to show the exact character of the rock bottom of the channel as the well sections furnish no evidence on this point. It may be mentioned, as having some bearing on the history, that a rock shelf comes out from the base of the hills north of Enterprise and extends about 20 feet underground to the present river channel. Just across the river wells are reported 60 feet deep and showing that here as at Rockport there is a deep filled valley.

During the pre-Lafayette period the land stood at about its present level, and the Ohio River cut out the valley shown in Fig. 5. This period was followed by the Lafayette submergence when the sands and gravels were laid down as an estuarine deposit and the valley probably assumed about the appearance shown in Fig. 6.

During the post-Lafayette or Ozarkian period the land stood more than 70 feet higher than now and the river after cutting through the Lafayette sands and gravels cut deep into the underlying Carboniferous rocks (Fig. 7); cutting from side to side it took away the Lafayette gravels in places along the side of the river leaving deposits only here and there. Then followed another subsidence and the river filled up its channel making a broad alluvial flood plain. At some time after the post-Lafayette high level the loess was deposited on the bluffs on either side making them 15 to 30 feet higher. This gives the valley of the present (Fig. 9).

Figure 9 is a diagrammatic representation of these earth oscillations of the Ohio valley during the Lafayette part of the Neocene and the Pleistocene, the Columbia submergence being based on the supposed aqueous origin of the loess of this region. Only the vertical movement is here represented as no data bearing upon the time covered in each movement was collected.

It should be noticed that this record of continental oscillation agrees very closely with the record of the Mississippi embayment, as given by McGee.[1]

ARTHUR C. VEATCH.

INDIANA UNIVERSITY,
Bloomington, Indiana.

[1] U. S. Geol. Sur., 12th Ann. Rep., 1890, p. 429.

THE BROWN OR YELLOW LOAM OF NORTH MISSISSIPPI, AND ITS RELATION TO THE NORTHERN DRIFT.[1]

OUTLINE.

I. General characteristics of the Brown or Yellow Loam.

II. Its stratigraphic relations and its distribution in north Mississippi.

A. Its relations to the Lafayette.

Unconformity between the Brown Loam and the Lafayette proper indicated by:

(1) The fact that wherever the Lafayette occurs in force, covered by the loam, the greater part of the present surface relief is due to the irregular contours of the Lafayette, rather than to varying thickness of the former, resulting from recent erosion: topographic relief of the Lafayette greater than that of the Brown Loam.

(2) (*a*) The feathering out of the Lafayette, and its alternate disappearance and reappearance eastward and northeast from Oxford, Miss., thus leaving erosion remnants intercalated between the Brown Loam and pre-Lafayette formations.

(*b*) The presence in the surface formation of northeast Mississippi, where, in many places, the Lafayette is now absent, of materials similar to those of the Lafayette where typically developed.

(3) The degree of oxidation produced in the Lafayette prior to the deposition of the Brown Loam.

(4) The occasional presence of thin patches of a seemingly distinct formation intercalated between the two, composed of materials similar to those of the Lafayette, but unconformable alike with the Lafayette below and with the Brown Loam above, thus indicating, probably, *two erosion intervals* of greater or less duration between the time of the deposition of the Lafayette and that of the Brown Loam.

(5) The character of fossil plants found in bowlders of clay in this intermediate formation, near Oxford, Miss., and derived presumably from the Lafayette.

Summary: The preglacial age of the Lafayette.

B. Its relation to the Loess (oı Bluff formation of Hilgard).

III. Origin and age of the Loess Loam.

A. Lower limit of the formation in north Mississippi.

B. Upper limit in the same region.

C. Conditions under which the formation was deposited.

D. Subsequent alteration.

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[1] This paper is based upon a series of personal observations extending continuously from Riverton, Alabama, to Memphis, Tennessee, in a crescentic curve passing

I. GENERAL CHARACTERISTICS OF THE BROWN OR YELLOW LOAM.

The predominant material of the formation in this section to which Hilgard has applied the name of brown loam, or yellow loam is as he states (*Agriculture and Geology of Mississippi*, p. 198), "that of a mellow clay or loam, without any definite structure or cleavage, variously tinged with iron; containing from 10 to 25 per cent., usually, of siliceous sand, the rest being clay mixed with finely divided silica, and forming, therefore, rather loose, mellow soils, and good brick clays.

The loam proper of this formation varies from the brownish-black color of our richest upland soils, where the coloration is due largely to the presence of organic matter through yellow and red, to the grayish-white "buckshot," or "crawfish," lands, which are ill suited to agricultural purposes.

In view of the immense value of these "buckshot" (which characterize the lands of that name by their presence in large number) to the geologist in enabling him to identify with reasonable certainty loams of this period occurring in this region, a brief description of them will not be out of place. They are not confined to the so-called "buckshot" or "crawfish" lands, but

through the counties of Tishomingo, Prentiss, Union, Lee, Pontotoc, Lafayette, Yalobusha, Panola, Tate, Marshall, and De Soto in Mississippi, and Shelby county, Tennessee.

In its preparation invaluable aid has been received from the writings of Hilgard, McGee, Chamberlin, and Salisbury. To my former instructors in field geology, Messrs. A. P. Brigham, H. B. Kümmel, and T. C. Chamberlin, credit is due for valuable training in field methods; to Professors Chamberlin and Salisbury I am also indebted not only for instruction in the theoretical aspects of the science, but for suggestions as well, given both in and out of the class room, bearing upon the subject under discussion; and to Professor Chamberlin I am under special obligations for a critical review of the first draft of this article.

Thanks are also due to Mr. Charles Strong, M.A., former Fellow in Chemistry, University of Mississippi, for a chemical analysis of "buckshot" from the yellow loam; to Dr. F. H. Knowlton, for the identification of fossil plants herein described, and to various others for kindnesses shown me.

But for the collection and collation of data on which this paper is based, and for the conclusions derived therefrom, I alone am responsible. The accompanying photographs were taken by Sanders and Sweeney, Oxford, Mississippi.

are liable to be found, in smaller numbers, wherever the Brown Loam occurs, and one will rarely travel far in the loam region without finding them. They seem to be entirely characteristic of the Brown Loam in this vicinity, not being found in any of the older formations on which it directly rests—that is, as far as my observation extends—and over most of the territory the loam is itself the surface formation. It is true that along streams frequently "second bottoms" are to be found (sometimes as "buckshot" lands), and the more recent alluvial deposits, the latter, however, never containing concretions: but the former are undoubtedly, in many cases, merely terraces of degradation cut in the Brown Loam, when, because of increased velocity due to increase of slope or to decrease of burden, or to both, the streams began to erode the bottoms of their channels more rapidly than their sides, and so ceased to overflow only within the past twenty-five or thirty years.

But it is not always an easy matter in the field to separate the loam from more recent formations. This subject will be more fully treated under the head "Upper Limit in the same Region."

These "buckshot" are usually more or less rounded, yellowish-brown on the oxidized surface, black in the interior, possessing no definite structure, and ranging in size from that of a small shot to that of a small marble. Not infrequently, however, they are much larger, when they usually tend to become more flattened and angular, and are frequently found cemented by iron oxide into a rather friable conglomerate.

These ferruginous concretions have undoubtedly been formed by segregation from the mass of the loam, as have somewhat similar ferruginous concretions and the calcareous nodules from the loess, and especially the friable conglomerate already mentioned, has evidently been cemented *in situ.* (Compare paragraph 338, p. 199, *Agriculture and Geology of Mississippi.*) Typical specimens of the "buckshot" from the loam of Tate county, ground up together and analyzed at my request by Mr. Charles Strong afforded:

	Per cent.
Silica (SiO_2), - - - -	78.55
Ferric oxide (Fe_2O_3), - -	14.88
Water, - - - - -	1.51
Sulphuric acid (H_2SO_4), - -	1.03
Lime (CaO), - - - -	1.944
Alumina (Al_2O_3), - - -	2.06
Total, - - - -	99.974

Perhaps the most notable characteristic of the brown loam is its general disintegrated, "rotten" appearance, with the entire absence of anything simulating stratification in the loam proper, notwithstanding the fact that the particles composing it are usually fine and such as ought, it seems, to have been neatly stratified if deposited under ordinary conditions, and not subjected to subsequent atmospheric and aqueous action. This subject will be more fully discussed under the general head, "Origin and Age of the Loess-Loam."

II. STRATIGRAPHIC RELATIONS AND DISTRIBUTION OF THE BROWN LOAM OF NORTH MISSISSIPPI.

According to Hilgard (*Agriculture and Geology of Mississippi*, pp. 197–198), "the yellow, brown, or reddish loams which have been repeatedly mentioned as forming the surface, and therefore essentially, the soils of the greater portions of the State of Mississippi constitute to all appearance an independent aqueous deposit, posterior to the Orange Sand (Lafayette) and the Bluff formation, and anterior to the alluvial formations of the present epoch. The great thickness which this loam stratum attains in some regions, its distinct definition as well as its comparative independence as to its character of the formations immediately underlying, preclude its being claimed as a mere surface disintegration of the older formations. The nature of its materials and the entire absence of stratification lines distinguish it sufficiently from the Orange Sand where it immediately overlies the latter; while the absence of any large amount of lime, except where it is in immediate contact with strongly calcareous formations, the presence of a considerable amount of hydrated peroxide of iron as well as the want of proper fossils as distinctly separate it from the Bluff formation of the Mississippi River. . . . .

"From the appearance of the loam stratum, even on high ridges and elevated uplands, it is obvious that its deposition took place, in part at least, anterior to the great denudations which have produced the present surface configuration; nevertheless, its increasing thickness as we approach the immediate valley of the Mississippi shows, as in the case of the Bluff formation, that this great channel was already in existence.

"On the Tombigbee, and on the lower Tallahatchie, Yalobusha, and Big Black, a similar increase in the thickness of the loam stratum may be observed. But on the smaller water courses this is the case only to a very limited extent, showing that, although at the time of the deposition of the loam the channels were already more or less impressed upon the surface and high ridges existed which remained above the level of the water which deposited the loam, the minor denudations which have caused the present undulating surface had as yet exerted but little influence. The lines of contact between the Orange Sand and Loam, where the latter is evidently *in situ*, are generally much less undulating than are those between the Orange Sand and the older formations."

A. *Relation of the Brown Loam to the Lafayette.*—From the foregoing account, it would appear that the Brown or Yellow Loam proper is a formation *sui generis*, deposited on a previously eroded land surface in such wise as not to turn aside the larger preëxistent streams, and distinguished from the Lafayette only by "the nature of its materials, and the entire absence of stratification lines where it immediately overlies the latter." These criteria for the discrimination of the Brown Loam and the Lafayette will, of course, fail of application (1) where there is no great difference in the nature of the materials of the two formations, as is frequently the case, especially near their line of contact, and (2) where the upper part of the Lafayette, as well as the Brown Loam, is unstratified.

Wherever the loam attains a thickness of 10 or 12 feet—and it is rarely thinner than this for any considerable distance—it is usually not difficult to identify it, especially its upper portion, but, as Hilgard has long ago pointed out, this formation is frequently so modified by underlying terranes as to render its delimitation in those places a matter of great difficulty, if not impossible. For instance, locally the characteristic loam may be replaced by sand variously colored; and when all traces of stratification, if they ever existed, have become obliterated through the action of percolating chalybeate waters, which both color and cement the sand grains, and when this red, sandy phase of the "Brown Loam" or "Yellow Loam" rests directly upon similar sands of the Lafayette—whence the former have generally been derived—it frequently becomes a matter of impossibility to draw any certain line between the two. This is often the case in the "red lands" of the Pontotoc Ridge and its northward continuation, the "Buncombe Hills." However, judging from an exposure near the depot in the town of Pontotoc, and from numerous other sections on the ridge, both the brown loam and the Lafayette seem to be represented in the Pontotoc Ridge; but as we shall presently see, the Lafayette is frequently absent in northeast Mississippi, the Brown Loam resting directly upon still older formations.

A section in the cut on the Illinois Central Railroad just south of the depot at Oxford shows typical loam at the top, grading into rotten or friable clay, which, becoming more sandy below, passes insensibly into a semi-indurate, massive red sandstone. The base of the section here shows nicely stratified sands and clays, presumably of Lafayette age, though possibly later, but no definite line can be drawn between the two formations at this exact point.

While we cannot always with certainty determine, in the field, the limits of the two formations, and while there are to be found places of seeming local conformity, which we should naturally expect, still the two can generally be separated without difficulty, because, when typically developed, the two formations possess little in common. And from such good exposures I have obtained strong evidence of great and widespread unconformity between the Brown Loam and all older formations. A great erosion interval is indicated by the following facts:

1. A considerable interval of erosion between the Lafayette and the Brown Loam periods is indicated by the fact that wherever the two occur in force the greater part of the present surface relief is due to the irregular contours of the Lafayette rather than to varying thickness of the post-Lafayette resulting from recent erosion. In other words, the topographic relief is greater in the Lafayette than in the post-Lafayette. This is indicated by the greater thickness of the post-Lafayette in existing valleys than on hilltops, even where there has been no recent deposition in the former of loam washed in from the hills. Many Lafayette hilltops, frequently capped with ferruginous sandstone bowlders, seem to have been above water continuously since Lafayette times. It seems that the land in this region has not been under water long enough since the period of Lafayette erosion to allow the complete filling in of the channels cut in the Lafayette; and this is partly due to the fact that deposition was taking place simultaneously, though not to so great an extent, over the greater part of the hills and ridges into which the Lafayette had been cut. And so the most of our present streams, especially the larger ones, are of the superimposed type—superimposed by sedimentation.

The greater deposit of sediment in the valleys is probably due to the fact that the valleys were submerged for a longer time, but partly also to the greater effect of their deeper waters in the checking of currents and consequent precipitation of sediments.

2. Another line of evidence of unconformity between the Lafayette and the Brown Loam, closely related to the one just given, lies in the fact that the Lafayette frequently feathers out, leaving the Brown Loam to rest directly upon the formations older than the Lafayette. Sometimes the evidence of the former extension of the Lafayette over the area in question is not con-

clusive, as where the Brown Loam rests directly upon the pre-Lafayette formations, and there is no trace of the Lafayette left in the vicinity, it is impracticable under such circumstances to say whether the Lafayette once covered the given locality and has been entirely removed by erosion, or whether it was never present. Such a state of things is exhibited in many places in the country near New Albany, Miss., and elsewhere. The Brown Loam mantles the hills and dales of this region, resting in many places directly upon the Cretaceous, sometimes upon the Lafayette, as it does elsewhere (as we shall presently see) upon the Lignitic Tertiary, and as it does regularly upon the Lafayette further westward. It cannot be a surface disintegration of the Cretaceous at this place; but it is seen to be directly continuous with the loam stratum elsewhere observed, and was without doubt formed at the same time and in the same way. (As to the geological relations of the surface soil, Brown Loam, in this region, see also *Ag. & Geol. of Miss.*, paragraphs 335, 336, and 337, pp. 198–199.)

But sometimes the Brown Loam rests upon older formations once covered by the Lafayette, which has subsequently been removed by erosion. There are two lines of evidence: (*a*) Near Oxford, Miss., where the Lafayette is typically developed, it attains a maximum thickness of something like 200 feet. But towards the east it soon thins out, exposures of the Lignitic being quite common within eight or ten miles of Oxford.

As the region of Flatwoods is approached, the Lafayette becomes discontinuous, and patches of it only are to be found intercalated between the Brown Loam and the Northern Lignitic. The Lafayette seems to give out altogether several miles before the Flatwoods are reached. At the exact western limit of the Flatwoods, some ten miles west of Pontotoc, on the Pontotoc and Lafayette Springs road, several feet of typical brown loam are seen to rest directly upon the blue clays of the Lignitic. Over the Flatwoods region, here six or seven miles wide, both the Brown Loam and the Lafayette are usually absent, the latter always, the former occurring in limited patches towards its eastern border. Both formations seem to be found again in the Pontotoc Ridge and Buncombe Hills, as already noted; but the Lafayette soon gives out and seems not to appear again, at least not strongly and typically developed. For example, over the greater part of Union, Prentiss, and Tishomingo counties, the Brown Loam rests upon formations older than the Lafayette. Frequently the Brown Loam has been removed by erosion, and the "Rotten" Limestone, Selma, or Tombigbee Chalk comes to the surface. Exposures of this latter formation are quite common in the prairie region, as is well shown around Booneville, Baldwyn, Marietta Springs, etc.

On a hilltop about fourteen miles from Booneville and sixteen miles from Iuka, on the old Booneville and Iuka road, several feet of Yellow Loam repose directly upon stratified, blue, pyritiferous clay of the Eutaw (?) group.

At Bay Springs, in southwest Tishomingo county, the Brown Loam rests either directly upon Sub-Carboniferous sandstone or there is a thin intervening stratum of pyritiferous Eutaw (?) clay — the source of the chalybeate waters of the springs. (*b*) While there is plenty of orange-colored sand in east Prentiss and in west Tishomingo counties, nowhere in this region did we find materials of undoubted Lafayette age *in situ*, though it seems likely that the Lafayette once covered this area, and that small patches of erosion remnants may still exist, because materials similar to those found in the Lafayette further west are here found to a greater or less extent scattered irregularly through the Brown Loam. The quartzose pebbles of Tishomingo county, for example, described by Hilgard (*Ag. & Geol. of Miss.*, 1860), and referred to the Lafayette epoch, seem to occupy an entirely different stratigraphic position from the majority of those in the western region, *i. e.*, from Memphis, Tenn., to Grenada, Miss., and southward, which are evidently of Lafayette age. In the former region these pebbles are found intermingled with the Brown Loam, as shown in many places near Iuka and elsewhere, while in the latter region they are invariably below the Brown Loam, sometimes in apparent local conformity with its base, elsewhere well within the Lafayette The gravels of this western belt were all evidently first transported to this region and deposited during the Lafayette epoch, and towards its close, though in many places they have been subsequently moved locally and redeposited at the base of the brown loam. On the principle of homogeny, the gravels of the eastern belt are thought to have been brought down originally at the same time with, and in the same manner, as those of the western region; but owing to the complete, or almost complete, removal by erosion of the Lafayette in the eastern region, these gravels have been shifted from their original positions and redeposited within the Brown Loam, and by the same waters (for I hold the Brown Loam to be essentially an aqueous deposit) which deposited the finer materials of the brown loam. These waters need not have been swift in order to transport pebbles, for these were probably only locally shifted and let down from higher to lower levels. On the other hand, the fineness of the materials of the bulk of this formation gives evidence that the formation, as a whole, was deposited by sluggish currents overloaded with fine sediment.

And so an application of the principles of homogeny, as defined by McGee (*12th Ann. Rep. U. S. Geol. Surv.*, p. 381 *et seq.*) to the Brown Loam of the whole of north Mississippi, together with the fact that undoubted erosion remnants of the Lafayette are to be found as far east as the Pontotoc Ridge, would seem to demand the former extension of the Lafayette over the whole of the area in question. A comparison of the hypsographic distribution of existing patches of the Lafayette with the hydrography of the region strengthens this conclusion, since remnants of the Lafayette are to be found on the highest hills, while on lower lands near by, the Lafayette may be entirely absent. As to the original thickness of the Lafayette, we have no way of determining this; but the evidence, direct and indirect, just presented, indicates a considerable erosion interval between the Lafayette and the Brown Loam during which a large part of the former had been removed prior to the deposition of the latter.

3. The degree of oxidation and attendant phenomena produced in the Lafayette prior to the deposition of the Yellow Loam, by atmospheric and aqueous agencies, likewise tell the story of a considerable interval of chemical as well as mechanical erosion between the periods represented by these two formations. (See *Am. Jour. Sci.*, Vol. XLI, p. 370.)

4. The facts already presented show conclusively that a long period of erosion intervened between the time of deposition of the Lafayette and that of the Yellow Loam. Over most of the area embraced within the scope of this paper the Lafayette seems to be essentially a continuous deposit, with the Yellow Loam resting directly and unconformably upon it, although its irregular stratification and the alternating layers of coarser and finer material indicate varying local conditions such as would result if the formation were deposited in the manner supposed by Hilgard.

McGee finds evidence in some localities of a twofold and even of a threefold division of the Lafayette, the divisions being separated by "pseudo-unconformities," which, according to him, represent only local shifting of currents, and consequent change in deposition, and do not mark the limits of distinct episodes. (*12th Ann. Rep. U. S. Geol. Surv.*, pp. 453–456, and elsewhere.)

But sections observed by the writer have caused him to doubt the unity of the Lafayette, as now defined in its type locality, and to raise the question whether the uppermost member of the Lafayette may not represent a distinct formation.

Occasionally there is found a stratum of clay and sand, or of clay alone, intercalated between the main bulk of the Lafayette and the Yellow Loam, and sharply separated from both by irregular or billowy erosion lines. This deposit is usually only a few feet in thickness, and consists, (*a*) of compactly bedded pipe clay, (*b*) of interlaminated clay and sand (the different layers sometimes quite thin, sometimes several inches thick), or (*c*) of a heterogeneous, unsorted mixture of sand and clay bowlders of various shapes and dimensions, resembling very much in physical characteristics, the unsorted till of the North.

An excellent illustration of the first is found in an exposure of some thirty or thirty-five feet, four and one-half miles south of Chulahoma, Marshall county, Mississippi. Here we find several feet of compactly bedded pipe clay, with a billowy upper surface, covered by eight or ten feet of Yellow Loam—from which it is quite sharply separated—and resting upon a decidedly eroded surface of cross laminated Lafayette sand. The three formations are distinctly traceable for perhaps a hundred yards, when the surface of the Lafayette descends so far as to be no longer exposed. Stratigraphically and lithologically the three formations are here very distinct, and show no evidence whatever of grading into one another. The erosion line between the clay and the sand is as sharply defined as that between the clay and the Yellow Loam. This clay, moreover, gives evidence, in its irregular streakings of ferric oxide, of having once been highly fossiliferous, and this evidence is strengthened by the fact that it still contains a few leaves in a fine state of preservation. These fossils were evidently formed *in situ* and not plucked from older formations and redeposited. Not enough were found to be of any practical value in determining the geological age of the clay stratum in which they occur, and those found have not been identified. Of the specimens in my collection at least two distinct species are represented, the one having a very small netted veined, linear-oblong leaf, resembling a willow leaf, or the leaf of a water oak, the other also netted veined, oblong-ovate, and entire, but much larger than the first, being about an inch broad by two and a half inches in length. If the formation in question belongs to the Lafayette, then the Lafayette here contains fossils of its own in its upper part; but it appears to belong to a distinct epoch or episode, and the presence of fossils in clay would seem to indicate conditions of deposition different from those which appear to have obtained when the Lafayette sand, directly underneath, was being deposited.

The accompanying photographs represent a continuous section one-third of a mile north of the depot at Oxford, Mississippi. A cut in the Illinois Central Railroad at this place, giving an exposure of thirty to thirty-five feet, shows a section very similar to the one just described, except that the middle member here consists of eight to twelve feet of clay bowlders, large and small, rounded and angular, mixed indiscriminately with sand. This section shows:

FIG. 1.—Section near the depot at Oxford, Mississippi, showing two members of the Columbia Formation and their relation to the Lafayette. (*a*) Yellow Loam; (*b*) fossiliferous clay bowlders and sand; (*c*) cross-laminated Lafayette Sand.

(*a*) At top, 0–8 feet of Yellow Loam.

(*b*) 8–12 feet of clay bowlders and sand.

(*c*) At base, 0–12 feet of cross stratified Lafayette sand.

Here the three formations are very distinct lithologically, and there is no evidence of the gradation of one into another either in a lateral or in a vertical direction.

The top stratum (*a*) is a typical loam, while (*b*) consists of sand mixed with clay bowlders, rounded and angular, varying in size from mere pellets up to slabs one to two feet thick, four to six feet long, and of unknown width, but presumably of not more than a few feet. The lowest stratum (*c*) has been sufficiently described above.

This bowlder stratum (*b*) consists of rock materials similar to those of the directly underlying or adjacent Lafayette; so from a lithological standpoint two views of the origin of this stratum are possible. Either it and (*c*) have been derived from the same pre-Lafayette formation, or formations, and the apparent unconformity between them is to be regarded as a "pseudo-unconformity," as explained by McGee, or the two are distinct formations, and the upper one has been derived from the lower.

The latter I regard as the more probable for the following reasons:

1. The extent to which the underlying sands have been eroded, and the very abrupt change from cross laminated sands (seemingly a local delta deposit) underneath, to a bowlder stratum of the character described—these seem to indicate extraordinary conditions of deposition for the bowlder stratum, and an amount of erosion of the underlying formation, which could not be accounted for by a mere local shifting of currents, with no appreciable changes of level nor consequent interval of erosion.

Smaller clay pellets, it is true, occur quite frequently elsewhere, in the body of the Lafayette, but never so large, as far as I am aware, as those just described.

2. The size of many of these bowlders, and their frequent angularity (which may be due in part, however, to subsequent atmospheric action), as well as their composition and physical texture, render it highly improbable that they have been transported by running water for any considerable distance.

The Lafayette proper is about 150 to 180 feet thick in this vicinity, as shown by recent well borings; and the Lignitic, the immediately underlying deposit, comes to the surface only at a distance of several miles to the eastward. A well recently bored upon the university campus, after passing through a few feet of surface loam penetrated the Lafayette formation, and

FIG. 2.—Northward continuation of Fig. 1. (*a*) here removed from center of photograph by erosion. Talus at base composed largely of fossiliferous clay bowlders from (*b*).

reached the Lignitic beds at a depth of about 180 feet. Wells in Oxford struck the same beds at depths of 155 to 160 feet.

The pipe clay of which these bowlders are composed is also of an unctuous, kaolinic nature, such as would not seem able to suffer prolonged transportation by running water without disintegration.

3. The clays of this bowlder stratum are altogether unlike those of the Lignitic beds near here, which are generally blue, or black, pyritiferous, and friable when dry. But the clays, also, of the Lafayette proper, which must have come from a distance, show a like dissimilarity to the Lignitic clays, having become altered probably in color and relieved largely of carbonaceous matter and of iron pyrites (if they came from the Lignitic) during transportation or subsequent to their redeposition. So the argument based on the dissimilarity of the clay bowlders to clays of pre-Lafayette age in this vicinity is of no value considered apart from the conditions under which they must have been deposited, and the short distance to which they could have been transported by running water.

4. These bowlders are frequently highly fossiliferous, containing plant specimens preserved in ferric oxide, and prolonged water transportation, if possible, would probably have defossilized them by the removal of the iron oxide in solution. The fact that no well-defined fossils peculiar to itself have yet been found in the Lafayette might be adduced as evidence that these fossiliferous bowlders must have come from some other source (and the character of the fossils as described by Dr. Knowlton would seem possibly to indicate their derivation from an earlier formation); but this does not necessarily follow, since plants must have existed during the Lafayette, and if none have been found in it the explanation is probably to be found in the fact that its materials, as a rule, are not well adapted to the preservation of organic remains. Its clays, moreover, as already pointed out, are very similar to those of the stratum under discussion, and the latter are very rarely fossiliferous. It is only occasionally that we find fossils in compact, close-textured, impermeable and

highly colored clays. Where there has been freer circulation of water, and where roots of recent plants have penetrated them, these clays have become more friable and partially decolorized, the change from their former condition being indicated, as already noted, by the peculiar distribution of the remaining ferric oxide, which frequently retains the shape of stems and leaves but not their texture. And in many instances such markings are traceable by the lighter color and by the more disintegrated condition of the clay where fossils seem to have existed, the ferric oxide having been, it seems, more completely removed, subsequently, than from the surrounding clay. Much care, however, is needed in the interpretation of many of these tracings, part of which are due to the action of roots of recent plants, part to the collection of ferric oxide on slickenside surfaces resulting from the jointing of the clay and the scratching of joint surfaces by their movement over sand grains. Such markings frequently give a fluted appearance resembling very much the impressions of parallel veined leaves.

The foregoing considerations, it seems to me, render it highly improbable that the coarser and clayey materials of this peculiar bowlder conglomerate could have been transported for the distance of several miles by running water.

The peculiar admixture of sand with clay bowlders, large and small, rounded and angular, with no trace of sorting, suggests to the writer the possibility of this deposit having been formed after a partial reëlevation succeeding the Lafayette subsidence, by the sapping of the banks of a small post-Lafayette lake or stream.

The inability to discover similar plant remains in the adjacent Lafayette might be explained by the removal of the original beds by plantation.

It is barely possible that this particular deposit may have been made by floating ice during the first interglacial epoch (or more probably during the first interglacial episode of the first glacial epoch), and I shall present, later, evidence of iceberg action at this time, in this vicinity—but the elevation of this deposit above the larger water courses, such as the Tallahatchie and Yocona rivers, between which it lies and down whose swifter waters most of the icebergs probably traveled, renders it hardly probable that the deposit was formed in this way.

According to Professor Chamberlin the Natchez formation occupies similar relations to the Lafayette and to the Loess of the northern Mississippi, though it contains crystalline pebbles in addition to materials derived from the Lafayette; and he suggests that both may have been formed at the same time, the two representing a distinct episode, or epoch, between the Lafayette and yellow loam.

On this hypothesis there was a period of upheaval succeeding the Lafayette deposition, during which all formations then existing were greatly eroded. This was followed by subsidence in the region of the lower Mississippi, accompanied by the deposition of the Natchez formation and of the stratum between the Lafayette proper and the Yellow Loam in this vicinity. Then followed an interval of upheaval and erosion, marked by the irregular contours of the upper surface of the bowlder stratum of the Oxford section and by the presence of an old soil at the summit of the Natchez formation. It is not to be understood, however, that the supposed Natchez subsidence was great enough to submerge the areas in question below sea level, for the deposits have not the characteristics and distribution which would probably have resulted from the action of ocean waves.

The deposits were probably formed when the land surface was at a comparative base level, and are of fluvial and lacustrine origin, and not marine, nor even estuarine. The amount of geological time represented by this hypothetical oscillation (during which the Natchez formation and its supposed congener in this vicinity were deposited and subsequently eroded prior to the deposition of the Loess and the Brown Loam) is probably very short, though it serves to emphasize the time interval between the Lafayette and the Brown Loam.

5. Other evidence bearing on the age of the Lafayette, and

therefore upon that of the Yellow Loam, is that furnished by the character of fossil plants found in the bowlder bed at Oxford previously described. The value of this evidence, however, is diminished by the fact that it is not absolutely certain that they came from the Lafayette formation. These fossils are mainly leaves and small stems, and occasionally an acorn (?), of what "seems to be a new and very fine species of Quercus" (Knowlton); and sometimes there is found a specimen of a palm, that "is with little doubt Flabellaria Florissanti, Lx, found originally in the Eocene of Colorado" (Knowlton). The preserving agent is apparently red hematite which shows up the smallest veinlets of the leaves. Indistinct traces of grass-like plants are also to be found. In answer to inquiries as to the probable age of these fossils, as referred to the accepted geological time scale, and the probable climatic conditions then prevailing, as indicated by the nature of the plants, Dr. Knowlton has this to say: "The data upon which to base an opinion of age is, as you see, quite too scant for a positive assertion. I should say, however, that it indicated rather an Eo-Lignitic than later age. Could it be possible that the clay in which the plants occur was a pocket or lens which had been torn from the Eo-Lignitic and redeposited in the Lafayette? However, I incline to the opinion that they are Eocene rather than later, but more material will be needed to confirm or disprove this . . . . the above mentioned plants do not indicate any marked change from the climate of the present day . . . . I imagine that when the fossil flora is thoroughly studied we shall find that species or forms have persisted for long periods of time with comparatively little change."

This paper deals with the study of the Lafayette formation only to the extent necessary for fixing the lower limit of the Yellow Loam. And the foregoing evidence of unconformity between the two is adduced in corroboration of the evidence presented by Chamberlin and Salisbury (*Am. Jour. Sci.* Vol. XLI, p. 359 *et seq.*) in favor of the preglacial age of the Lafayette. The proof of the glacial age of the Loess of the Mississippi valley, presented by them in the article just referred to, appears conclusive.

I have shown that the Yellow Loam occupies the same position with reference to the Lafayette in the interior, that the Loess does along the Mississippi valley. By the foregoing considerations, and by a review of the relation of the Yellow Loam to this loess in this vicinity, I hope to strengthen the evidence already presented by McGee that the Yellow Loam and the Loess are not only homotoxial but that they are also genetically related.

B. *The relation of the Brown or Yellow Loam to the Loess* (*or Bluff formation of Hilgard*).—These two deposits were discriminated by Hilgard, who considered them as separate formations, the Brown Loam being the younger (*Ag. & Geol. of Miss.* 1860).

Later, McGee and others have noted the somewhat complex relations of the two along the bluffs of the southern Mississippi, especially around Vicksburg and Natchez (*12th Ann. Rept. U. S. Geol. Surv.*, p. 392 *et seq.*).

The present paper has nothing to do, except in a very general way, with this area, concerning which McGee says: "The loess of the lower Mississippi region may be characterized as a peculiar condition of the Brown Loam, or as an imperfectly demarked phase of the great formation into which both deposits fall." Having reached the same conclusion from a study of the area embraced within the scope of this paper I shall now proceed to state the grounds on which this opinion is based:

1. The Drift of the North is the surface formation, to which the loess of the river valleys bears an ascertained and definite relation, as already noted. During the Glacial period there were extensive continental oscillations during which, according to some authorities, the whole southern part of our continent was submerged: so, on *a priori* grounds, we should find as the "southern equivalent of the northern Drift" a mass of water-deposited sediment more commensurate in quantity with the Drift than is the Loess alone. Evidence of such submergence will be brought out in the further discussion of this subject.

2. Having traced the surface formations from Bear Creek, on the Alabama-Mississippi-Tennessee lines, to the Mississippi River at Memphis, and to the "bluffs," 40–50 miles below, I found the loess and the loam to be absolutely continuous, the former usually being absent, or not characteristically developed, except within a few miles at most of the existing "bluffs" and frequently in the "bluffs" themselves replaced entirely, locally, by loam, with characteristic ferruginous "buckshot," to the very base.

The following characteristic sections will serve for illustrations:

A. *Sections at Memphis, Tenn.*—(*a*) Bluff just north of Custom House; at base, typical bluff-colored loess, non-effervescent throughout its mass, but containing characteristic concretions, calcareous and ferruginous, — the latter tubular or cylindrical rather than rounded—and obscure fossils. This passes laterally into yellow or brown loam, and also becomes loamy at the top—as the loess quite frequently does. Evidently the loam here is only modified loess, or the latter is only a peculiar phase of the loam. This is the most characteristic exposure of the loess observed at Memphis. Going down the river both fossils and concretions (of the loess proper) become less frequent. (*b*) Section about one-half mile north of the river bridge; 60–70 feet (estimated) of typical brown loam with its characteristic "buckshot" to the very water's edge, where it rests unconformably on the Lafayette—the loess being entirely absent. Exposures near here show a loess-like loam devoid of fossils and concretions. (*c*) Section about one-third mile north of river bridge. (1) At top 60–70 feet of loam. (2) White and reddish sand, cross laminated, and containing occasional pebbles, sometimes stratified, 10 feet. (3) Stratified Lafayette gravel, 2–3 feet exposed. The lowest 5 or 6 feet of (1) are pronouncedly sandy, the upper part of (2) humus stained, indicating an old soil. (*d*) Section about 30 yards south of the last. Here we have about 60 feet of yellow loam, with "buckshot" at its very base, resting directly upon stratified

Lafayette gravel, No. (2) of the preceding section being absent.

B. *The relations of the Loess and the Brown Loam along the "bluffs" of southwest Tate and northwest Panola counties.*— In this region the bluff is much higher, though far less precipitous than at Memphis, where it is being continuously washed at its base. The estimated height of the rampart at Askew's Bluff, northwest Panola, is 200 feet. But thence it diminishes in altitude both northward and southward. Concretions and fossils are generally to be found in abundance within a few hundred yards eastward from the present base of the rampart in this region, but no clear cut section showed in any one place the characteristics and the relations of the Loess from the top down to the Lafayette. However, a continuous, descending section from the summit of Askew's Bluff passes over several feet of gravels, similar to those at Memphis and southward, about two-thirds of the way down. Further down, the blue clays of the Lignitic are struck and something like 40 or 50 feet are exposed; and one-quarter mile north, in a ravine, there is found a seam of cheesy lignite one or two feet thick. Traced eastward from this point the loess passes insensibly into the surface loam. The main body of the Loess here, as elsewhere, is as a rule, less disintegrated than the Yellow Loam; but the formation is apt to be more loam-like at the top, where most exposed to atmospheric action.

Traced northward the Loess seems to maintain its typical character as far as studied, *i. e.*, to the road running west from Senatobia. Proceeding eastward along this road from the bluff, here quite low, the shells soon disappear from the Loess, but limestone concretions were found as far as four or five miles from the foot of the bluff, at a point one mile east of Strayhorn. Between these two places the Loess frequently alternates with loam, and at one place, about one and one-half miles west of Strayhorn, limestone concretions and ferruginous "buckshot" were found associated together in a sort of loess-loam, which became more loamy at the top. Here, as frequently, the limestone concretions assume dendritic forms, caused evidently by percolating calcareous waters in ramifying crevices. Specimens were taken from such crevices.

No microscopic examination of the loam was made for comparison of its mineralogical constituents with those of the loess; but owing to a greater degree of subsequent alteration in the former it seems doubtful whether such tests when made would prove entirely satisfactory. The chemical composition of the two, in their typical development, seems to differ rather in degree than in kind, from the same cause, and the two pass into each other by insensible gradations.

From the foregoing it would appear that, if my observations be accurate, the Brown Loam and the Loess of this region are not only homotaxial but synchronous as well.

III. ORIGIN AND AGE OF THE LOESS LOAM.

The Loess of the north has been distinguished as belonging to two separate epochs, and a similar twofold division of the same in the south is mentioned as a probability by Chamberlin and Salisbury, in an article entitled "On the Relationship of Pleistocene to the pre-Pleistocene formations of the Mississippi Basin, south of the limit of glaciation" (*Am. Jour. Sci.*, Vol. XLI). The Yellow Loam is here considered as the interfluvial equivalent of the Loess, but the writer has seen nothing to suggest, or which would justify, the division of the former into two or more parts, separated by a time interval of greater or less duration. On the other hand, sedimentation generally seems to have been continuous from the beginning to the close of the period —the first deposits, frequently composed mainly of local and coarser materials, being directly followed by the finer deposits which constitute the main bulk of the formation. It does not follow that the Yellow Loam formation may not be of a bipartite nature elsewhere; and if it should prove universally indivisible this need not antagonize the idea of a twofold division of the Loess, because owing to elevation, or other causes, there may have been no interstream deposit here contemporaneous with one epoch or the other of the Loess, the deposition of which seems to have been confined to the vicinity of the river courses at that time.

I may call attention, however, to the fact that in section *c* of the bluff at Memphis, as previously described, a humus stained horizon, indicating an old soil, was found at the upper surface of number 2, but this seemed to me to be the upper surface of the Lafayette, and not a part of the Loess-Loam at that place.

Because of the evident twofold division of the Loess in the north we should naturally expect the same for the Loess in the south, and perhaps for its interfluvial equivalent, the yellow or brownish surface loams. But this does not necessarily follow, for reasons stated above, and the results of my observations, considered without regard to exposures which I have never seen in other localities, will not justify me in an attempt to subdivide the Loess-Loam formation of this region. The formation is, therefore, considered in its entirety and the question of its delimitation discussed more fully in the following paragraphs.

A. *Lower limit of the Loess-Loam.*—This subject has already been discussed more or less fully in the description of the stratigraphic relations of the Brown Loam. The first Glacial epoch is divided by Chamberlin and Salisbury (*Am. Jour. Sci.*, Vol. XLI, pp. 362–363) into two episodes, and the inferior member of the Loess is referred to the close of the second Glacial episode of the first Glacial epoch. From the foregoing evidence it will be seen that the Brown Loam cannot be earlier, and that it is the interfluvial equivalent of at least one, perhaps of both, divisions of the Loess. And neither seems to be the full representative, in the South, of the northern Drift. The Natchez formation was probably deposited during the first Glacial episode of the first Glacial epoch, and towards its close, and I have given reasons above for believing that the same episode is represented in north Mississippi by scattered patches of subaërial deposits. These deposits, as already noted, are composed of local material, and while they may be contemporaneous with the earlier Drift, they are not genetically related to it, as the Natchez formation along the river is said to be.

The Brown Loam and its substratum in many places in this vicinity show a remarkable similarity to the Columbia formation of McGee as described at its type locality. Yet the facts recited above suggest that perhaps the Pleistocene history of the lower Mississippi may not be so simple as he has pictured it. But it is important to note, in this connection, that evidence of a distinct episode between the Lafayette and the Brown Loam is confined to the more inland and higher counties, such as Marshall and Lafayette. Further west such a deposit, if it ever existed, has been removed, and here, too, the Lafayette if it were ever thick has been almost entirely removed, leaving only a few feet of gravel and sand between the Loess and the Lignitic beds, as is the case at Askew's Bluff, Panola county. In the bluff at Vicksburg, too, in some places, only a few feet of such gravel intervene between the Loess and the Vicksburg limestone of the Tertiary.

Relation of the gravel deposits of north Mississippi to the Loess-Loam.—These gravels, in the main, are considered as primarily belonging to the Lafayette, but in many places they seem to have been worked over and redeposited in the Loess-Loam, or at its base, near their original location. The difference in the stratigraphic position of the pebbles of the eastern and western belts has already been noticed. In the former region, most, if not all, the pebbles have been worked over. These also contain a much higher percentage of chert pebbles—sometimes quite large and angular, or subangular—derived from adjacent Sub-Carbonifereous chert deposits.

The gravels of the western belt are found most frequently at the base of the Loam or Loess. Generally it is not practicable to determine whether they belong to the Loam (or Loess), or whether to the top of the Lafayette. But occasionally a few feet of Lafayette sand intervenes between the gravel bed and the surface formation. At the Memphis bluff, as we have seen, the gravels belong undoubtedly to the Lafayette. At a point eleven miles from Batesville, on the Batesville and Water Valley road, the following relations were observed: A hill mantled with several feet of loam, which becomes thicker down the hill-side and in the adjacent valley; near the hilltop the underlying Lafayette sands contain scattered quartz pebbles, while further down the hill, at a considerably lower level there is a well-defined pebble stratum at the base of the loam. Toward the hilltop the pebbles are evidently well within the Lafayette, while toward the bottom of the hill the pebble stratum seems to form the basal member of the Loam, though it is undoubtedly derived from the higher level gravel of the Lafayette (compare the relations of the Loess to certain gravels in southern Illinois *Am. Jour. Sci.*, Vol. XLI, p. 366 *et seq.*).

Similar gravels have been described by Professor Salisbury (JOUR. GEOL., Vol. III, pp. 655–667), from Devil's Lake, Wisconsin, where they underlie the Drift. They are therefore of Pre-Glacial age. Direct correlation of this deposit with the southern gravels is at present impossible, but it seems probable that both were laid down by the same "definitely limited set of agencies" acting within "a definitely limited period of time"—a period closed by the inauguration of the Glacial period in the North.

As to the conditions under which the Lafayette was deposited, I do not feel prepared to speak. However, it seems to me that Hilgard's view as stated in "The Age and Origin of the Lafayette Formation" (*Am. Jour. Sci.*, No. 257, Vol. XLIII), on the whole, is to be preferred; only we must look to another source than melting continental glaciers, for the floods which brought down and deposited the materials of the Lafayette.

B. *Upper limit of the Loess-Loam.*—This formation covers by far the greater part of the surface in this region, and it is only in the "second bottoms" and in the bottoms proper that we find materials of a possibly later age. Many of these "second bottoms" are simply low, broad terraces of degradation carved out of the Yellow Loam, as already noticed. Others are probably stream terraces of constructive origin. But as such deposits are confined to the vicinity of streams, deposition along streams proceeding *pari passu* with erosion of the general surface of the country; and because the materials of such terraces have been derived wholly or largely from the Loess-Loam, and both formations being usually unstratified, we have no certain means of discriminating the two. And, indeed, the necessity for such discrimination seems very slight when we remember that the formation of these stream terraces began immediately after, or coincidently with, the general uprising which brought the Loess-Loam period to a close; and that they are local lowland deposits formed during a period of general elevation and erosion, rather than general deposits formed during a period of depression. The important point to remember is that the whole of the area under discussion has never been under water since the period of depression during which the Loess-Loam was deposited, and that the interval of general erosion, and "loss of record," which has existed here since the deposition of the Loess-Loam is represented by the contemporaneous deposits of lakes, streams, and adjacent shore lines. Geological history written on tablets of ocean bottom is comparatively easy to read, but written by lakes and rivers upon a scratched and mutilated continental surface, it forms a palimpsest very difficult to decipher by the aid of stratigraphy alone. As an evidence of the truth of this statement I desire to call attention to the different views prevailing among geologists as to the age of the low level deposits known as the Port Hudson group. Some consider this as the oldest of southern Pleistocene formations, others believe that it corresponds to the last epoch of glaciation. With this formation, however, the present paper does not deal, since these deposits are not to be found within the area under discussion. Loess has not been found, I believe, in the North corresponding to the Drift of the third Glacial epoch, yet it does not follow that the Mississippi did not continue to bring down drift material during this time which may have been added to previous deposits of loess or loam.

Nor can we say that this process may not have continued for some time after the final retreat of the ice beyond the Canadian line. If we consider that the Glacial period began in the United States when the land ice from Canada first crossed the

Archæan highlands between Canada and the United States, eroding in some places and in others depositing till; and if the final retreat of the same ice mass beyond the same highlands be considered as marking the close of the Glacial period, how shall we fix the limits of a formation in the south derived largely from glacial débris? Such deposits, no doubt, are still forming to some extent near the edge of the drift-covered area; and the deposit of till in the North must have begun in advance of the deposition of the Loess-Loam, and of the Natchez formation.

We may only say that the Loess-Loam in this region is homotaxial with the drift, that being composed largely of drift materials it cannot antedate the latter and that the two were in a general sense synchronous.

C. *Conditions under which the formation was deposited.*— For a discussion of the conditions under which the Loess-Loam was deposited the reader is referred to *12th Ann. Rep. U. S. Geol. Surv.*, pp. 401–404.

This formation is to be considered as being essentially a flood-plain deposit of glacial débris (worked over to some extent perhaps by the wind), and formed during a period of subsidence, when the whole surface of the country in this region was practically at sea level. The submergence of the surface seems to have been so slight that fresh-water conditions prevailed over marine, and currents laden with glacial débris ran far southward into a tideless bay. Indications, however, of brackish, or of marine conditions, are to be found in the present "salt-licks" which occur quite frequently in the Yellow Loam of some localities, such as Tate and Panola counties.

In the absence of shore lines to mark this incursion of the sea, evidence of submergence is to be found in the areal and vertical distribution of the formation, which no other causes seem competent to explain. Still more direct evidence is afforded by the presence in some localities of huge foreign bowlders imbedded in, or at the base of, the Yellow Loam, and which, it seems, could only have reached their present positions by iceberg action, or through some supernatural agency. A very interesting deposit of siliceous sandstone blocks is found at Rockyford, Union county, Mississippi, twenty-two miles east of Oxford. Along the hills on either side of Tallahatchie River, near the village, blocks of hard white or gray sandstone either rest directly upon the soil (the prevailing position), or are loosely imbedded in sand. Some of these bowlders will weigh, perhaps, 300 or 400 tons, and many of them present square cut surfaces as if just plucked from some parent ledge. These extend for about one-half mile only on each side of the river. The nearest bed rock at all like these blocks is a Sub-Carboniferous sandstone found in southern Tishomingo county some fifty or sixty miles distant and across the Tallahatchie-Tombigbee divide, on the headwaters of the latter. These bowlders must have been brought down by icebergs from the north, or possibly from the northeast, coming down the Tennessee River valley and across the divide between this and the Tallahatchie, into the latter, where they deposited their load by melting or by overturning.

A smaller block of angular fossiliferous chert, weighing 150 or 200 pounds, was found at the juncture of the Lafayette and the Yellow Loam at a point about seven miles east of Senatobia, in Tate county.

Similar bowlders are reported from other parts of the State, but with these I am not personally familiar.

Absence of stratification in the Yellow Loam may be due in part to its deposition from sluggish currents overloaded with fine detritus (see "Conditions of Sedimentary Deposition," JOUR. GEOL., Vol. I), but the subsequent alteration of the deposit seems generally to have been great enough to have destroyed all traces of stratification which may have existed.

D. *Subsequent alteration.*—In the study of this formation it seems to me that the idea of great chemical alteration subsequent to deposition has not been properly stressed. The fact is evidenced by the present decayed appearance of the loam proper, and by the surface alteration of the loess; by the segregation of part of the lime and iron in the former into "buckshot" and in the latter into calcareous and ferruginous nodules. At the contact plane of the former with older formations — the Lafayette around Oxford, or the Northern Lignitic a few miles east — there are frequently selvedges of "hardpan," or ferruginous sandstone, sometimes of considerable size, and occasionally containing a high percentage of iron. These are not to be confounded with similar "iron ores" of the Lafayette. That the loess has suffered less alteration than the loam is evident. The present difference between the two may be due partly to original difference in chemical composition and physical texture, but more largely I think to a difference in degree in subsequent alteration. The latter may be attributed to the difference in thickness of the two, which would both give to the loam a higher percentage of organic matter (derived from older soils), which on decomposition would furnish abundant solvent for its soluble constituents, and also allow a freer circulation of water for the accomplishment of the decomposition of putrescible matter and consequent leaching of the loam.

The roots of existing plants, too, may penetrate through the loam as they could not always the loess. But the Memphis sections would seem to indicate, also, original local differences in chemical composition and physical texture.

T. O. Mabry.

University of Mississippi.

CLASSIFICATION OF THE MISSISSIPPIAN SERIES.

Because of its vast array of finely preserved fossil forms, the Mississippian or Lower Carboniferous limestone series, has, since the beginning of geologic investigation in the Mississippi valley, aroused great interest. At an early date the fossils of the successive beds were studied, and were illustrated in the geological reports of Iowa, Illinois, and Missouri, and formation names were given to the various strata. In the final adjustment of the work of all the earlier investigators, the following formation names, from the base upward, came to be recognized, (1) Kinderhook, (2) Burlington, (3) Keokuk, (4) Warsaw, (5) St. Louis, and (6) Kaskaskia or Chester. Each one of these divisions was held to be of equal importance with all the others, essentially, and until recently this original, more or less artificial, classification remained in vogue.

The true classification of rock strata and fossil faunas is but an incident in the elaboration of the geologic history of a region, and in order to make a natural classification of these phenomena, they must be considered from a historical standpoint. The classifications of rock strata which have been generally used, are based upon two distinct sets of criteria, (1) stratigraphic, and (2) faunal. A stratigraphic classification by no means excludes the fossil evidence, and is based fully as much upon the differences observed among the fossil species of successive formations as upon the physical characteristics of the strata; but the fossils are looked upon in the same light as the physical characters, as a sort of label of the strata, rather than as a real life element subject to all the laws of organisms. The old classification of the Mississippian series into the six formations indicated above was purely stratigraphic in its nature, although great stress was laid upon the fossil contents of the various formations.

It is a universally recognized fact today, that assemblages of organisms are intimately related to the environment in which they live. With a change in the environment there will be changes among the associated organisms.

In no geologic province, such as the continental interior of North America during Carboniferous time, whose history must be considered as a unit, are the physical conditions of the whole area identical at any given time. Neither are the conditions of any one limited portion of the province, identical throughout an entire epoch or chapter in its history. Local changes in the physical conditions, and consequently in the local assemblages of organisms are continually in progress. A stratigraphic classification of rock strata is based upon these local changes in the sediments and their contained organic remains, and consequently can be of but local significance. In such a classification the profound physical changes which affect the whole geologic province in its relations with adjacent provinces, are given no greater importance than the comparatively insignificant local changes.

A natural classification of strata must be a faunal classification in its broadest sense. It is based not merely upon the identity or lack of identity of fossil species in the different local formations, but upon the minute study of the relationships of the assemblages of fossils in the successive zones of particular sections, and upon the study of the geographic distribution of species. All fossil species are either indigenous or exotic to the geologic province in which they are found preserved. They are either evolution species or immigration species, and the sudden appearance of exotic or immigration species in the fauna of a geologic province, shows, as nothing else can show, that the relationship between the province and its neighbors is undergoing a readjustment. In the history of any geologic province the distinct epochs or chapters must be limited by these periods of readjustment. Oftentimes these periods cover a considerable lapse of time and alternate with periods of quiet, in which case the periods of change and the periods of quiet are most naturally considered as distinct epochs.

A name applied to a historical epoch of a geologic province, is applicable as a stratigraphic name to all the strata deposited during that epoch. It may not always be possible to draw a sharp and fixed line in the stratigraphic series between two succeeding epochs, so that everywhere, throughout the geologic province the exact limits of the historical epochs may be pointed out. It is not necessary, for the establishment of an epoch name, to select, as the type, a section in which every stratigraphic and faunal phase of the epoch is illustrated. As a matter of fact it would be almost impossible to find a type section for most geologic epochs in which all its varied phases were exhibited. It is only necessary, in the selection of a geographic name for a geologic epoch, that some one or more phases of strata and fauna be well illustrated there.

In recent years, two classifications of the Mississippian series have been proposed. The first by Williams[1] is a natural faunal classification, while the second by Keyes[2] is a stratigraphic classification which is nothing more than a further elaboration of Hall's earlier one, uniting some of his divisions and dividing others.

Williams was the first to recognize in the strata and fossil faunas of the Mississippian series, the evidence of three distinct chapters in the history of the continental interior during lower Carboniferous time, and for these chapters or epochs he used the names (1) Chouteau, (2) Osage, and (3) Ste. Genevieve. The commonly recognized local geologic formations were placed, as accurately as was possible at that time, in their respective epochs, and further investigation seems to necessitate no different disposition of them. Of the three epoch names proposed, Osage and Ste. Genevieve were used for the first time. Chouteau, on the other hand, had long been used as a formation name for one of the local limestone strata in Missouri. The Chouteau group was made by Williams to include, beside the Chouteau limestone,

[1] Bull. U. S. G. S., No. 80, p. 169.

[2] Bull. Geol. Surv. A., Vol. III, p. 283; Iowa Geol. Surv., I, p. 50; and Missouri Geol. Surv., IV, p. 76.

several other local formations, and as the relationship between the faunas of these formations had previously been recognized, and the name Kinderhook applied to them all, it seems best to use the latter name instead of Chouteau for the first epoch.

In order to have a right understanding of the history of the continental interior during Mississippian time, it will be necessary to glance briefly at the events immediately preceding During the greater part of Devonian time, the eastern interior region of North America was occupied by the great Mediterranean Appalachian sea. This sea extended from the Laurentian land on the north to the western extension of the Appalachian land[1] on the south, and from the Appalachian on the east to the Missouri land on the west. The outlines of this sea were continually changing during Devonian time, and at intervals it was joined by open passages in different directions with the outer oceans. Near the close of the Hamilton epoch, a passage through the northwestern portion of North America was opened, by means of which communication was established between the Appalachian sea, and the Eurasian ocean. This northwest passage crossed northern Missouri, Iowa, and southwestern Minnesota, and extended northward through Manitoba and the Mackenzie Valley. The Chemung fauna of the Appalachian province contains an important element derived from the European faunas, an element which without doubt found its way into the Appalachian sea through this northwest passage.

Just before the opening of Mississippian time, the distribution of land and water in North America was about as indicated in Fig. A, the northwest passage being connected with the Eurasian province. The progress of events during the period was, first, an epoch of disturbance, of readjustment and sinking land; second, a long epoch of quiet and equilibrium, with widespread marine conditions ; and third, another epoch of disturbance with further readjustment between the interior province and its neighbors. These three epochs are: the Kinderhook, Osage and Ste. Genevieve.

[1] Proc. Bost. Soc. Nat. Hist., XXVI, p. 474; and A. J. S. (4), IV, p. 357.

The stratigraphic elements included in the Kinderhook group are varied in their physical characteristics. There are limestone, sandstone and shale formations. The formations are local in their distribution and characters, and consequently the different minor assemblages of organisms preserved in the strata

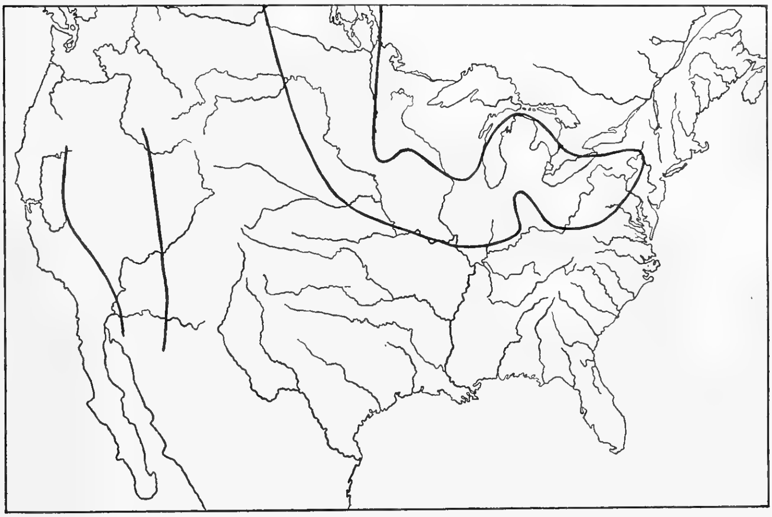

FIG. A.

are more or less local in their distribution. The Kinderkook fauna as a whole is known only in a very general way, no detailed investigation of it has ever been attempted. It is in many respects related to the Devonian faunas, and especially to that fauna which had found its way into the region from the northwest.

During the progress of the Kinderhook epoch the land was sinking to the south, and the southern shore line was migrating in that direction. The margins of the successively younger sediments transgressed further and further to the south over the ancient land surface. In central Missouri, strata of late Devonian age rest directly upon the old Ordovician land surface. In southern Missouri, strata of Kinderhook age occupy the same position, and in central Arkansas, in the region of the Ouchita uplift, the whole Mississippian series is absent, strata of Lower Coal Measure age resting upon the Ordovician beds.

The Kinderhook epoch of generally disturbed conditions, the epoch of readjustment, was followed by the Osage which was a

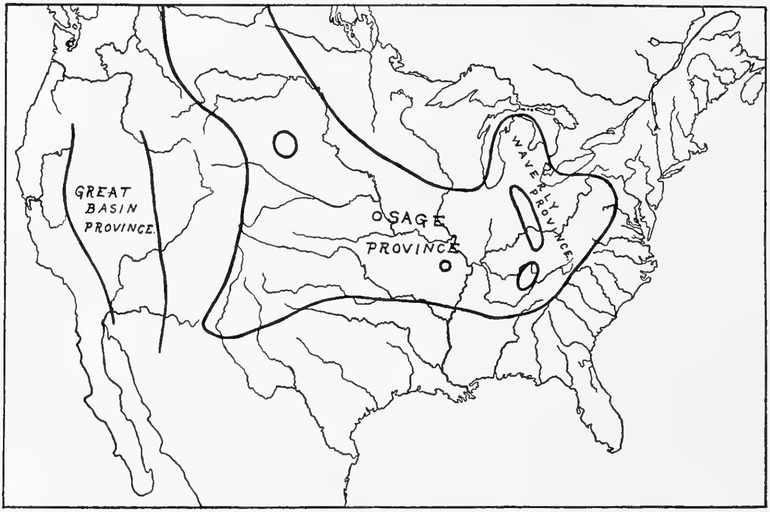

Fig. B.

long period of tranquillity. No longer were there sediments of various sorts being deposited in the interior sea. The surrounding land had sunk so low that practically no sediments were transported by the streams, and the only rock-making material furnished was the calcareous secretions of organisms. Crinoidal fragments constitute the major portion of this limestone, though the remains of corals and brachiopods are also abundant.

The probable distribution of land and water during Osage time is indicated in Fig. B. A great, quiet, interior sea extended from the Cincinnati island on the east to the Rocky Mountain land on the west, and from the southern Appalachian land to the Wisconsin land at the north. The northwest passage still furnished a means of communication with European waters.

The Osage is the best known of any of the Mississippian aunas. Hundreds of species of crinoids founded upon the most perfectly preserved specimens in the world have been described from these strata. Next in importance to the crinoids are the brachiopods, represented by many species. Besides these the corals and bryozoa are often abundant, but the remaining classes of organisms are relatively inconspicuous. The fauna has been most studied in Iowa, Illinois, and Missouri, but a good, crinoidal, Osage fauna has been described from southwestern New Mexico,[1] and crinoids certainly indicating the presence of the fauna have been described from near Bozeman Mountain.[2]

The Osage fauna has many points of resemblance with the fauna of the mountain limestone of western Europe. In each there is a large crinoidal and a large brachiopod element. Every genus of crinoids in the European fauna is represented in the American, and many species of brachiopods are common to both regions, though the American specimens have sometimes been given different names. The following is a partial list of identical or representative brachiopods in the two regions:

American species	European species
Athyris incrassatas H.	*Athyris roissyi* L'Eveille.
A. lamellosa L'Eveille	*A. lamellosa* L'Eveille.
Camarophoria subtrigona M. and W.	*Camarophoria isorhyncha* McCoy.
Chonetes illinoiensis Worthen.	*Chonetes hardrensis* Phill.
Dielasma hastata Sow.	*Dielasma hastata* Sow.
Dielasma sacculus Martin.	*Dielasma sacculus* Martin.
Leptæna rhomboidalis Wilck.	*Leptæna analoga* Phill.
Orthis (*Rhipidomella*) *burlingtonensis* H.	*Orthis michelini* L'Eveille.
O. (*Schizophoria*) *swallovi* H.	*O. resupinata* Martin.
Productus laevicostus White.	*Productus cora* D'Arb.
P. punctatus S. Martin.	*P. punctatus* Martin,
P. burlingtonensis H.	*P. semireticulatus* Martin.
Rhynchonella pleurodon Phill.	*Rhynchonella pleurodon* Phill.
Spirifer grimesi H. } *S. Logani* H. }	*Spirifer striatus* Martin.

[1] A. J. S. (3), XXVII, p. 97.

[2] Bull. Ill. State Mus. Nat. Hist., Nos. 10 and 12.

American species.	European species.
S. lineatus Martin. *S. lineatoides* Swall. *S. pseudolineatus* H.	*S. lineatus* Martin.
S. suborbicularis H.	*S. ovalis* Phill.
S. tenuimarginatus H.	*S. duplicicostus* Phill.
Syringothyris carteri H.	*Syringothyris cuspidatus* Martin.

The similarity between the faunas of the two regions is so great that some way of intercommunication must have been in existence. The presence in Grinnell Land[1] of a similar fauna, in some respects intermediate between the two, would seem to indicate a northern and then eastern passage-way between the interior American province and western Europe.

The physical changes, which initiated the interior continental province of Osage time, were of a different nature from the changes that had ushered in previous epochs in the history of the region; and as a consequence, the fauna of the Osage epoch falls into a different category from earlier ones. In no case were the changing faunas of the Appalachian province during Devonian time, to any great extent, indigenous in their origin. The Osage fauna, however, was apparently very largely native to the region. The western European faunas doubtless exercised their influence upon it, but the influence of the American fauna upon that of Europe seems to have been much the greater.

A large portion of the territory occupied by the Osage province had previously been dry land. A vast area of new sea bottom was formed by the sinking of the land. The marine organisms which were to inhabit the region were unhindered in their development. They came in contact with no previously existing fauna which had either to be driven out or to be absorbed into their own social organization. Their rapid growth and differentiation may be compared with the rapid development of a human civilization in a newly opened country with vast resources, where there is a place for everyone with strength and vigor, and where the close struggle of individual with individual does not

[1] Q. J. G. S. Lond., XXXIV, p. 568.

exhaust the vitality. While the close struggle for existence between individuals does seem to be a means of bringing about many minor differentiations of specific importance, the more important differentiations of generic or higher rank seem to be associated with conditions under which there is a wealth of resources, where the struggle is between the organism and the physical environment to a greater extent than between organisms and their nearly related fellows.

The characteristic features of the Osage fauna were assumed at its beginning. After this the struggle was to a greater extent between individuals, and the organic changes were of minor importance, being to a great extent of no more than specific rank.

That the influence exerted by the American fauna upon that of western Europe was greater than the influence of the European upon the American fauna, is shown by a comparison of the crinoidal elements of the faunas in the two regions. In the Osage faunas of America 50 genera of crinoids are recognized, and in the equivalent faunas of western Europe 21 genera. Of the European genera not a single one is peculiar to the region, each being also represented in America. On the other hand 29 genera are peculiar to the American fauna. Furthermore, of the genera which occur both in America and in Europe, a larger number of species are known in America than in Europe. These facts seem to show that as between the two the point of origin or of major distribution of this crinoidal fauna was in the continental interior province of America, and that in the course of its existence it probably migrated from this province into other regions.

During the time when the broad expanse of the clear waters of the Osage sea was the most conspicuous feature of North America, there were in existence at least two other and smaller geologic provinces in which different physical conditions prevailed, and which were inhabited by very different assemblages of organisms. The first of these, the Waverly, lay to the east of the Osage province, between the Cincinnati island and the

Appalachian land, and extended from Michigan through eastern Ohio and western Pennsylvania south to the Ohio River. There was direct communication between this and the western Osage province, and during the Kinderhook epoch there was a considerable community of faunas, but at no time did the clear water conditions of the Osage sea extend into the Waverly gulf. Consequently the clear water Osage species did not generally flourish in the Waverly province, though enough have been recognized to show that the Waverly series is practically the equivalent of the formations of the Kinderhook and Osage epochs combined.

While the interior of the continent was sinking and the Osage sea was spreading out towards the Rocky Mountain land, the land on the northeastern border remained well above sea level. Under these conditions abundant clastic sediments were continuously furnished to the northeastern Waverly gulf, but the long Cincinnati island extending north and south across its mouth prevented the spreading of the sediments into the clear waters of the Osage sea beyond.

In the western part of the North American continent, lying between the Rocky Mountain land on the east and the Californian land on the west, was the Great Basin province. In this province there had been no important change in the passage from Devonian to Carboniferous time. While in the interior of the continent there was but a short interval, the Kinderhook epoch, during which an apparent mingling of Devonian and Carboniferous species is observed, in the Great Basin province Devonian species continued to live, associated with others of Carboniferous types, long after they had disappeared in the Osage province.

Following the prolonged quiet of the Osage epoch in the interior, there was another long period of readjustment and change, which culminated in the elevation of the greater part of the region previous to the deposition of the widespread millstone grit formation which initiated the Coal Measures. This was the Ste. Genevieve epoch. In the far west the barrier between the Great Basin and the interior provinces was submerged, allowing the incursion of the Great Basin fauna with its persistent Devonian species into the interior. This recurrent Devonian element in the faunas of the interior, first definitely recognized in the Spring Creek limestone from near Batesville, Ark.,[1] is the faunal mark of the initiation of a new chapter in the geologic history of the continental interior. This element is characteristic of the St. Louis fauna wherever it exists. One of the best known of the St. Louis limestone faunas is that of the Spergen Hill beds in Indiana, and in this fauna the recurrent Devonian element is recognizable in the species of *Microdon*, *Conocardium* and *Nuculana*, genera which had disappeared from the interior of the continent during the Osage epoch. Although the Spring Creek and Spergen Hill faunas are quite different in many minor details, they possess many species in common, showing their relationship. In addition to this resemblance of the Spergen Hill fauna to the Spring Creek fauna, which is closely allied to the Great Basin fauna, a fauna practically identical with that of the Spergen Hill beds has been recorded from the far northwest in Idaho,[2] an occurrence which suggests the possibility of its immigration into the interior from that direction.

During the latter part of the Osage epoch there was apparently an emergence of the northern shore line in the region of Iowa, because the younger beds of the Osage group do not extend so far north as the older ones. With the beginning of the Ste. Genevieve epoch, however, this was all submerged again, and the St. Louis limestone strata extended farther to the north than the immediately preceding ones. This submergence was followed by a considerable reëlevation at the north, the Kaskaskia beds being deposited only in the southern portion of the province. The successive changes, more or less abrupt, in the sediments of the Ste. Genevieve group from limestone to sandstone, to shale and back again to limestone, etc., indicate

[1] Am. Jour. Sci., XLIX, p. 94.

[2] A. J. S. (3), V, p. 383.

that rapid and relatively violent local changes were in progress throughout this whole period of readjustment.

The fauna of the Ste. Genevieve epoch in all its varied phases is but imperfectly known, but it apparently contains, throughout, in greater or less degree, the western element suggestive of the prolonged Devonian, which first makes its appearance in the St. Louis limestone fauna, and continues on even into the faunas of the Coal Measures.

In the geologic history of our continent during Mississippian time, many details remain to be elaborated, and with the elaboration of these details our conception of it may be altered in some respects. It is believed, however, that further investigation will but make clearer the general features as outlined here. The threefold classification of the Mississippian strata, based upon the actual geologic history of the region as told by the fossils and by the geographic evolution, is seemingly the only natural one.

An attempt has recently been made[1] to substitute the name Augusta for Osage. The two names have been proposed for practically the same stratigraphic series, but in their proposal the two authors seem to hold very different conceptions of the criteria which should be used when the classification rises above the mere grouping of beds of a local character. The name Osage was proposed for a definitely recognized chapter in the geologic history of the region under consideration, while Augusta was proposed as the name of a special stratigraphic division composed of certain local formations. Hair-splitting distinctions between the exact limitations of groups of beds—however necessary in local and minor classifications—can have no decisive weight in the case, when the higher purpose of major classification, as an expression of the vital features of the history of the region, are duly considered.

Stuart Weller.

The University of Chicago.

[1] Am. Geol., XXI, p. 229.

EDITORIAL.

AMONG the incidental effects of the war between the United States and Spain will be an awakening to geographic and geologic relations. Even while war was but an anticipation there was not a little brushing up of rusty geography. Now that it is on the study will begin in earnest. And there is need of it. Not a few prognoses of the coming campaign, gravely announced and seriously discussed by the press correspondent, or the public functionary, or the club oracle, have been little less than absurd through their neglect of geographic relationships. Among the masses, and even among people of education, forecasts of quite possible eventualities of the war have been commingled with imagined eventualities which geographic relations altogether prohibit. Even to those fairly well informed the awakenings of the war will bring the rectification of many a false impression and not a little accession of fresh geographic knowledge. Just at this moment when one Spanish fleet is reported to have left Cadiz and another St. Vincent, and their destination is a matter of intense solicitude, it will perhaps come as a revelation to most of us that the Cape Verde Islands are nearer Boston than is Cadiz; that they are nearer Maine than Cuba; that St. Vincent is less distant from every American port on the Atlantic coast than it is from Havana. Both Spanish fleets when they set sail (if indeed they did) were nearer all our Atlantic ports than they were to Admiral Sampson's fleet.

There is, therefore, ample occasion for brushing the dust from our atlases and for the application of rule and compass to them with due regard to the mode of map projection. Beyond question the people of this republic will very generally become better instructed in the geography of the north-central

Atlantic and the north Pacific. They will take a new lesson in geography under the impulse of a grewsome interest and a solicitous intensity not equaled since the early sixties. And the public press with all its faults and errors will become one of the most effective teachers.

But even recourse to the best atlases will leave room for the rectification of erroneous impressions unless used with a circumspection not often realized. Recourse to the globe is to be urgently recommended. Every household which seeks to surround itself with convenient means for promoting an accurate intelligence of the great historical events of the passing days may well provide its living room with a globe—not necessarily large or expensive, for six-inch globes of fair accuracy and detail are in the market at seventy-five cents apiece. Institutions would do well to buy these by the dozen and use them for all sorts of diagrammatic purposes. The globular presentment is the true presentment of the earth; the map is its false presentment in more than a rhetorical sense.

To some extent public interest will extend to geologic factors. The distribution of coal is confessedly a pivotal element in the contest and the natural sources of coal, as well as its commercial distribution, will become familiar to thousands to whom such facts, under conditions of peace, would appeal only with indifference. The special configurations of the American and Spanish coasts are certain to be studied with peculiar intensity. The phenomena of sunken channels, of inlets and harbors, of spits and bars, of reliefs of the land and like features of military significance, will all take on an intensity of interest correspondent to the great issues which may hang upon the aid or the hindrance these features may give in the determination of results.

The actual contact with geographic and geologic phenomena into which the hundred thousand young men, more or less, will be brought as the result of the impending campaign will be to them, and through them to others, a geographic education of no little moment. It was observed at the close of the Civil War that those who returned from its campaigns possessed an appreciation of the elements of position and physical relationship quite beyond that realized by the preceding generation educated under the benign influences of peace.

These incidental contributions to our favorite sciences and to those elements of education that are associated with them will be among the compensations to be set over against the calamity of war. T. C. C.

Reviews.

PROFESSOR SPRING ON THE PHYSICS AND CHEMISTRY OF SOLIDS.

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Eine Bemerkung über die Arbeit des Herrn H. Le Chatelier. Zeit. f. Phys. Chem. 9, p. 744

The prime importance to the geologist of all investigations upon the relations of matter and force at great temperatures and pressures makes it profitable, perhaps, to review the work of Walther Spring on this subject. Professor Spring is the pioneer in this field. All his conclusions and theories on the chemistry and mechanics of solid bodies are founded upon a long series of careful experiments, in the course of which he has kept substances under great pressure for periods of more than twenty years, and these furnish us almost the only trustworthy information we have on the subject. It is of especial importance to call the attention of American geologists to this work of Professor Spring, as some discredit was thrown upon his work by M. W. Hallock in a contribution published in *Bulletin 55* U. S. Geol. Survey called "The Flow of Solids, or the Behavior of Solids Under High Pressure." The critic fell into an error through a mistranslation or a misapprehension of the French language,[1] especially translating "se souder" as to melt, and through his failure to grasp the fact that there may be a molecular diffusion in substances in the solid state.

Professor Spring's development of the subject was gradual and followed the advance of his experiments, so that a chronological review of his papers will give us a good exposition of his theories. In his first paper,[2] which was preliminary, he raises the question how sedimentaries harden where there has evidently been no cementation. He states that he has been able to press perfectly dry $K\ NO_3$ and $Na\ NO_3$ under a pressure of about 20,000 atmospheres into semicrystalline masses harder than the fused substances. Two years later he contributed his first important paper on the subject,[3] which contains,

[1] Simple observation au sujet d'un travail de M. W. Hallock intitulé: "The Flow of Solids," etc. Bull. de L'Académie Royale de Belgique. 3me série, 45, 1887, p. 595.

[2] Note préliminaire sur la propriété les fragments des corps solides de se souder par l'action de la pression. Bull. de L'Académie Royale de Belgique. 2me série, 45, 1878, p. 746.

[3] Sur la propriété que possèdent les corps solides de se souder par l'action de

besides his own valuable results, an excellent résumé of all the different theories concerning regelation. From experiments upon all kinds of chemical compounds he develops the following:

1. All solid bodies tend to consolidate under pressure, and this tendency is a function of the malleability of the substance or, in other words, an inverse function of the internal friction.

2. Pressure aids in consolidating or welding solid bodies because it makes an intimate contact.

3. Bodies capable of assuming crystalline form tend, under pressure, to weld so that the mass has a single crystallographic orientation.

4. Welding under pressure is caused by an actual molecular diffusion in the solid state similar to that in liquids, but far less active.

5. Pressure aids diffusion merely by bringing the particles into intimate contact with each other.

6. The reactions of solids upon solids are equilibrium reactions, and therefore chemical action under pressure tends to go in the direction which gives the smaller volume. Therefore, since the crystalline state is generally that which takes the smallest volume, pressure aids crystallization.

In two succeeding articles he states that solids, as well as liquids[1] and gases, are perfectly elastic volumetrically, that is, upon removal of pressure, the molecules vibrate with the same frequency as before and so the substance assumes its former volume. The only compression he could produce was caused by the crushing in of cavities, etc., and large contraction only occurred where new chemical compounds were formed, as where a new allotropic or polymeric form of the substance was assumed. The statement that matter takes an allotropic state corresponding to the volume which it is obliged to occupy has an exact significance. Moreover, the different states of matter all belong to one series—a liquid is an allotropic form of a gas—a solid of a liquid—a denser solid of a solid of less specific gravity.

This polymerization of molecules accounts for all changes of form and the more dense the polymeric forms, in every case the less active

la pression. Bulletins de l'Académie Royale de Belgique. 2^me^ série, 49, 1880, p. 323.

[1] Formation de sulphures métalliques sous l'action de la pression. 3^me^ série, 5, 1883, p. 492.

Sur l'élasticité parfaite des corps solides chimiquement définis. Analogie nouvelle entre les solides, les liquides et les gaz. 3^me^ série, 6, 1883, p. 507.

are they chemically. This last fact may partially explain the occurrence of chemically active substances uncombined deep within the earth. It is to be noted, however, that temperature acts in an opposite sense to pressure and for every allotropic state there may be a critical temperature above which it cannot exist no matter under what pressure.

In several following papers he explains experiments which confirm his previous conclusions on the diffusion of matter in the solid state. He finds that the velocity of diffusion depends upon three factors: (1) a constant peculiar to each substance and depending upon the velocity of molecular movements; (2) the temperature, with which the molecular velocity increases, and (3) the pressure, which makes the contact more perfect and tends to overcome the "surface tension" of the solid particles. He demonstrates that there is a critical temperature for the change of solids into liquids and mentions cases where liquids by increase of pressure have been changed into solids.[1]

In further experiments he finds that intimate contact caused by constant shaking without pressure causes diffusion between solids, and this diffusion takes place with extraordinary rapidity (three hours) at a higher temperature, though far below the melting point of either substance employed.[2]

In the article "Sur l'apparition dans l'état solide des certaines propriétés caractéristiques de l'état liquide ou gazeux des métaux,"[3] he recapitulates some of his former conclusions and presents new ones as follows:

1. Cohesion between fragments like that between drops of water must be overcome before diffusion between the two can take place.

2. The property of diffusion under pressure is not equally developed in all bodies and is best developed where internal friction is the least and where molecular velocity is the greatest.

[1] Réaction du sulfate de baryum et du carbonate de sodium sous l'influence de la pression. Bull. de l'Académie, etc. 3^{me} série, 10, 1885, p. 204.

Bull. de la Société chimique de Paris, XLI, p. 488.

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Comptes rendus, t. CV, 1887, p. 165.

[2] Sur la réaction chimique des corps à l'état solide. 3^{me} série, 16, 1888, p. 43.

[3] Bull. de l'Académie, etc. 3^{me} série, 28, 1894, p. 23.

Zeit. f. Phys. Chemie.

3. Pressure alone is not so efficient as when accompanied by an agitation of the particles which breaks their cohesion and aids diffusion. This explains cold welding, etc.

4. The three states of matter are only extreme degrees of a single ne and each has a critical pressure and temperature. Solids as well as gases and liquids have faster and slower moving molecules and this variation is the most extreme where the free path is the greatest, viz., at the surface, and therefore solid bodies in contact will weld at their surfaces when below the melting point, due to the interaction of the "liquid molecules."

5. The molecular mobility of a solid body is a function of the proportion of the rapidly moving portion (liquid molecules) to the whole number of molecules.

6. Crystalline bodies have a nearly uniform rate of molecular vibration, and therefore do not "solder" at a temperature much below melting, while amorphous or partially crystalline bodies with heterogeneous molecular motions weld easily.

Finally, in the contributions of the last few years[1] he has described some of his most remarkable experiments on this subject which confirm all his former conclusions. He kept perfectly dry powdered chalk under a pressure of from 6000 to 7000 atmospheres for seventeen years and three months. This same pressure acting through a short time only makes the chalk about as hard as ordinary writing crayon, but after this long time it was found as hard as marble. The fracture was conchoidal and the microscope showed it was crystalline. The steel screw which held the chalk under pressure had completely united to the cylinder, so that the cylinder had to be cut. The chalk was of a yellow ochre color to the depth of $1\frac{1}{2}^{mm}$, showing that the iron molecules had diffused $1\frac{1}{2}^{mm}$ into the chalk in about seventeen years.

This diffusion was at the ordinary temperature, but he has shown that at higher temperatures the velocity is much greater and "not only tends to complete the homogeneity of the solid solution, but also to cause an orientation of its molecules." These observations he applies as follows: "Les faits que j'ai observé contribueront peut-être à jeter

[1] Bull. de l'Académie, etc., 3me série, 1895. De l'influence du temps sur l'agglutination de la craie comprimée.

Sur les modifications physiques que subissent certains sulfures sous l'influence de la température. Bull. de l'Académie, 3me série, 1895, p. 311.

Zeit. f. Phys. Chem.

quelque lumière sur la question de la solidification des roches dans la nature. Ils peuvent nous faire comprendre pourquoi, en général, les roches les plus solides et les plus compactes sont aussi les plus anciennes, et ils peuvent nous expliquer la présence de ces milliards de cristaux microscopiques que l'on a observés dans certaines roches, par exemple dans les phyllades, cristaux qui paraissent s'être dévéloppés même après le dépôt des alluvions nécessaires à la formation de ces masses neptuiennes."

And again: "Cette observation ne me paraît pas sans conséquence pour certaines théories pétrographiques. En effet. s'il est déja possible d'observer un changement d'état physique dans un aggloměrat après onze années d'exposition à la température ordinaire, il est permis de penser que nombre de phénomènes de crystallization, voire de formation de numéraux, dans les roches agglomerées par la pression, aux dépens de matières à l'état solide, sans qu'il soit absolument nécessaire de faire entrevenir l'action de dissolvants quelconques."

He has also[1] experimented with the compression of dampened powders and finds in general that the insoluble bodies, such as metal filings, etc., do not solidify in the presence of water because the water prevents close contact. Soluble substances act differently—bodies whose solution takes less volume than the water and substance solidify more completely than in the dry state, while those whose solution is attended with an expansion of volume consolidate much better in the dry state. The explanation offered is that when the substance is more soluble under pressure, as pressure is relieved some of the material is precipitated into the interstices of the mass and it is solidified, while in the second case some of the matter is dissolved after the relief of the pressure, leaving a porous incoherent mass.

M. Le Chattilier[2] has noted this same fact that certain bodies in the presence of their saturated solutions solidify under pressure, and explains it a little more in detail as a case of equilibrium under heterogeneous pressure. The water is squeezed out of the mass and therefore is not under so great a pressure as the solid, therefore the solution next to the surface of the solid is supersaturated in respect to that farther away. This water then moving away from the solid precipitates and solidifies the rock.

[1] Zeits. für Phys. Chem., 2, p. 532. Über die Kompression von feuchter Pulver fester Körper und die Formbildung der Gesteine.

[2] Zeits. für Phys. Chem., IX, p. 335.

It has long been known that rocks suffer actual molecular movement if the forces act so slowly that they do not overpass the elastic limit of the rock, and again bodily movement must take place if the rock is subject to stresses greater than the ultimate strength of the rock, but the knowledge of the fact that solid matter has so much in common with gases and liquids is almost wholly due to the laborious investigations of Professor Spring, and these facts should immediately take their place in our theories of the condition of matter in the interior of the earth. C. F. Tolman, Jr.

United States Geologic Atlas, Folio 37. Downieville, California. 1897.

This folio consists of eight pages of text signed by H. W. Turner, geologist, a topographic map of the district, a map showing the areal geology, a map showing the economic features, a structure section sheet, and one page of special illustrations.

The quadrangle represented in this folio lies between parallels 39° 30′ and 40° north latitude, and 121° and 120° 30′ west longitude. It comprises a portion of the northern Sierra Nevada and lies in Plumas and Sierra counties. The area is drained by the forks of the Feather and Yuba rivers.

The formations are divided into two main groups, the bed-rock series and the superjacent series. The bed-rock series is composed of Juratrias and Palæozoic sediments and tuffs, and a series of old igneous rocks chiefly granites and porphyries. The Juratrias rocks comprise chiefly the Milton formation which is found only in the southeast portion of the quadrangle. The Milton formation, while formed of materials deposited under water, contains a large amount of igneous material. Underlying the Milton formation there are volcanic beds which are likewise presumed to be of Juratrias age, inasmuch as in the lower portion there are lenses of siliceous argillite, in one of which an ammonite was found. These volcanic beds are grouped as quartz-porphyry and as augite-porphyrite. The quartz-porphyry also occurs as dikes. The other igneous rocks forming part of the bed-rock series are granite, gabbro, and granodiorite. In the western portion of the quadrangle there are very large amounts of serpentine which have resulted from the decomposition of the pyroxene olivine rocks or peridotites and amphibolite which is the result of dynamo-metamorphism and hydro-metamorphism of augite-porphyrite. The rocks of the auriferous slate series comprise, besides the Milton formation just noted, an older set of rocks probably largely of Carboniferous age, as fossils of that age only have been found in them. These Carboniferous rocks are divided into two formations, the Robinson formation of late Carboniferous or possibly of Permian age, and the Calaveras formation, comprising rocks probably older than the Robinson formation.

The superjacent series consists of river slake deposits, moraines, and volcanic material. All of the rocks of the bed-rock series, both slates and igneous rocks, were greatly eroded during Cretaceous time and upon this old eroded surface there has been deposited by rivers of Tertiary age an extensive series of gravels, known as the auriferous gravel series. The river system of Tertiary time appears to be divisible into two distinct drainage systems with a divide between. This divide is represented by the high ridge of which the Sierra Buttes is the culminating point. The rivers to the west of this high north-south ridge drained southerly or southwesterly in Tertiary time as they do now. The deposits to the east of this Neocene divide appear to have been deposited by one large river which flowed north, draining into a basin to the north of the quadrangle. Superimposed upon these gravels, and at other points upon the older bed-rock surface, are extensive deposits of lavas, mostly in the form of breccias which have been very largely eroded. At one time these lavas probably covered nearly the entire surface of the quadrangle. They consist chiefly of andesites and basalts. The latest basalts, notably the kind forming the larger portion of Mount Ingalls, are possibly of early Pleistocene age. After the volcanic forces had subsided, portions of the region were occupied by glacial ice, resulting in the formation of very extensive moraines, which are finely seen on the east slope of the Sierra Buttes, about Gold Lake, and in the neighborhood of Johnsville. All of the lakes that lie on the east slope of the high ridge extending from the Sierra Buttes to Eureka Peak, are of glacial origin.

There are evidences of faulting in Tertiary and later time at various places in the district. The largest fault zone is that lying immediately west of Mohawk Valley. The faulting along the south and west sides of the American Valley, may perhaps be correlated with the same fault zone. As a result of this faulting the country to the east of the fault zone has subsided, resulting in the formation of the Mohawk and American valleys. Mohawk Valley, during early Pleistocene time, was occupied by a lake which has left terraces about the valley. These are finely preserved on the slope west of the north end of the valley.

Economic geology.— As economic features there are represented on the map numerous lenses of limestone, which is often highly magnesian. Gold quartz veins are indicated by orange dashes. The auriferous gravels are noted, and also deposits of chrome iron and of magnetite.

Bulletin of the American Museum of Natural History. Vol. IX, 1897.

This volume contains twenty-four separate articles contributed by members of the museum staff. Those from the departments of vertebrate and invertebrate palæontology will be briefly noticed.

Article IV. *Note on the Hypostome of Lichas (Terataspis) grandis* Hall. By R. P. WHITFIELD, pp. 45–46.

Lichas (Terataspis) grandis, is one of the largest and most highly ornamented trilobites of the Devoinan faunas. As yet it has never been found preserved except as fragments, and previous to the present paper no hypostome of the species has been described. This note by Professor Whitfield describes, with illustrations, two large hypostomes supposed by him to belong to this species. They are from loose bowlders of Schoharie grit obtained in northern New Jersey and are associated with other fragments of the same trilobite and with other species of the same horizon.

Article VI. *The Ganodonta and their relationship to the Edentata.* By J. L. WORTMAN, pp. 59–110.

The relationship of the Edentate mammals has long puzzled zoölogists, and previous to the establishment of the suborder *Ganodonta* by Dr. Wortman, no palæontologist has more than suggested what this relationship might be. Although the genera composing the group have long been known, yet the materials, up to the present time, have been so imperfect and fragmentary as to preclude any very exact knowledge of their affinities, and they have been placed by different authors at different times with the *Tillodontia*, the *Tæniodonta*, and the *Creodonta*. By the aid of the discovery of a fore limb of one of the species, *Pisittacotherium multifragum*, in association with the lower jaw and upper teeth, Dr. Wortman has been enabled to interpret the somewhat fragmentary remains of the other genera and to make out what he believes to be, not only their affinities to each other, but what is still more important, to demonstrate their genetic relationship to the later appearing American *Edentata*.

The genera included in the suborder are *Conoryctes*, *Onychodectes*, *Hemiganus*, *Pisittacotherium*, *Calamodon*, and *Stylinodon*. In the treatment of the relationship of these genera to the *Edentata*, seventeen points of resemblance are enumerated, and they are considered as a primative suborder of and the ancestors of the Edentates.

The South American Edentates appear suddenly in the Santa Cruz formation in great numbers and variety with apparently no previous announcement in the older deposits. This fact would seem to indicate that they were immigrants from another region. While the Santa Cruz beds cannot yet be accurately placed in the time scale, it is highly probable that they are not older than the North American Oligocene. In North America the *Ganodonta* appear in the very earliest Puerco deposits and continue without interruption into the Bridger, where they disappear.

If Dr. Wortman's conclusions as to the relationship of the *Ganodonta* to the *Edentata* be correct, as they seem to be, the geographic distribution of the groups would suggest that during Eocene time there was at least a temporary connection between the North and South American continents, allowing the immigration from the north, of the ancestors of the South American Edentate fauna.

Article XI. *Description of New Species of Silurian Fossils from near Fort Cassin and elsewhere on Lake Champlain.* By R. P. WHITFIELD, pp. 177–184. Plates IV–V.

The fauna of the Fort Cassin beds on Lake Champlain is one of remarkable interest. Its position is in the Lower Ordovician, in the upper part of the Calciferous formation. As a rule the Calciferous strata do not furnish an abundance of fossils, either specifically or individually, but the Fort Cassin beds are an exception. Two previous papers containing descriptions of species from this bed by Professor Whitfield[1] have appeared, so that in all 60 species are now known, distributed as follows, 25 gastropoda, 17 cephalopoda, 8 trilobites, 7 brachiopoda, 2 crustacea (not trilobites) and 1 bryozoan.

[1] Bull. Am. Mus. Nat. Hist., I, p. 293, and Bull. Am. Mus. Nat. Hist., III, p. 25.

Article XII. *Descriptions of species of Rudistæ from the Cretaceous Rocks of Jamaica, W. I., Collected and Presented by Mr. F. C. Nicholas.* By. R. P. WHITFIELD, pp. 185–196. Plates VI–XXII.

This papers contains descriptions with excellent illustrations of ten new species of these interesting fossils from Jamaica. Six species are referred to the genus *Radiolites*, and four to *Caprina*.

Article XX. *Observations on the Genus Barrettia* Woodward, *with Descriptions of New Species.* By R. P. WHITFIELD, pp. 233–246. Plates XXVII–XXXIII.

The genus *Barrettia* was established by Woodward, upon some peculiar cup-shaped fossils from the Cretaceous limestone of Jamaica, W. I., and was referred by him to the *Rudistæ*. Since the original description several authors have expressed doubts as to the correct reference of the genus to this group, and have questioned its molluscan nature, considering it to be more probably a coral.

Professor Whitfield's investigation of the genus is based upon a collection of these fossils, some of them of large size, sent to the museum by Mr. F. C. Nicholas. All of the characters, some of which were not observed by Woodward, are carefully summed up and the conclusion is reached that they are most probably corals. The paper is concluded by the description of two new species.

Article XXI. *The Huerfano Lake Basin, Southern Colorado, and its Wind River and Bridger Fauna.* By H. F. OSBORN, pp. 247–258.

The presence of Eocene beds in the Huerfano River basin of southern Colorado, was first made known, in 1888, by Professor R. C. Hills, of Denver. Three papers, published between 1888 and 1891, record the results of his observations upon the region. In the course of his investigation, the Huerfano series was divided into three divisions, beginning from the top as follows, (1) Huerfano beds 3300 feet, (2) Cuchara beds, 300 feet, and (3) Poison Canyon beds 3500 feet. The Huerfano beds were correlated with the Bridger group or Middle Eocene, on the basis if the vertebrate remains discovered, and the two lower divisions were provisionally referred to the lower Eocene from their stratigraphic position, no fossils being found.

At a later date the region was visited by Professor Osborn and Dr. Wortman, and the present paper records the results of their observations.

The two lower divisions, the Cuchara and Poison Canyon beds, were found to lie unconformably below the Huerfano beds, and from the presence of a species of *Baculites* it is supposed that they are Cretaceous deposits of marine origin. These Cretaceous beds were found to be certainly not 800 feet below the summit of the upper Huerfano beds, so that the observation affects not only the determination of the age of the Poison Canyon and Cuchara beds, but materially reduces the thickness of the upper beds.

The only true Huerfano lake deposits are variegated marls, clays, soft shales and sands, aggregating only 800 to 1000 feet in thickness, and lying in a nearly horizontal position. In these beds, although without doubt forming a continuous deposition, two distinct horizons were identified from their inclosed vertebrate remains. The upper one of these horizons, the one from which Professor Hills secured the major part of his material, is of Bridger age. The lower horizon, however, contains none of the forms characteristic of the Bridger level, but is distinguished as of Wind River or of Wasatch age, by the presence of several characteristic lower Eocene forms.

Article XXII. *A Revision of the Puerco Fauna.* By W. D. MATTHEW. Pp. 259–323.

The Puerco fauna was first described by Cope in numerous papers published between 1881 and 1888. Ninety-one species of mammals were recognized, and to these three more were added by Osborn and Earle in 1895. The original collections used by Cope are now the property of the museum, and to these have been added important collections made by the museum expeditions in charge of Dr. J. L. Wortman. The present revision is based upon all of these collections, and consists largely in a rearrangement of the species and a reduction of their number, made possible by the more perfect material.

The fauna of the upper Puerco beds is found to be entirely distinct from that of the lower beds, not a single species being common to both, and in no case does a genus pass through without serious modification of at least subgeneric value. Because of this difference in the faunas, Dr. Wortman proposes to designate the upper beds by the name Torrejon formation.

The Puerco-Torrejon faunas are composed of the following elements:

1. The Mesozoic group of Multituberculates culminates in the

Puerco and dies out in the Torrejon, true Rodents coming in to take its place.

2. The main body of the fauna is composed of primitive types from which sprang the Ungulates on the one hand and the later Creodonts and Carnivores on the other. In the Puerco these two divisions are hardly distinguishable, but in the Torrejon they are clearly separable, although still closely allied.

3. A few more specialized lines, the Edentata, Amblypoda and Rodents, with a fourth type allied to the Primates, may be separated from the main group.

A total number of seventy-five species is recognized in the whole fauna.

STUART WELLER.

Authors' Abstracts.

ABSTRACT OF PAPER READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.

Weathering of Alnoite in Manheim, N. Y. By. C. H. Smyth, Jr.

A somewhat altered dike of alnoite, consisting of biotite, serpentine, magnetite, perofskite, apatite, and some calcite, is exposed on the east bank of the East Canada Creek. Melilite, abundant in two neighboring dikes, is not apparent, doubtless being obscured by alteration.

On the west bank the dike is weathered to a fine yellowish-brown sandy clay, exposed about fifteen feet vertically. Under the microscope, the weathered material is seen to consist chiefly of biotite, magnetite, and perofskite, the other minerals being no longer recognizable.

From chemical analysis, it is evident that the rock in weathering has lost about 27 per cent., chiefly silica and magnesia, with less lime and potash. Alumina and titanic oxide show a relative gain in the same ratio, and are assumed to have remained constant. Iron also shows a relative gain, but slightly less than that of alumina, while it has undergone much oxidation. The amount of water has been very largely increased.

The greatest percentage of loss for a single constituent (excepting CO_2, which has totally disappeared) is shown in the case of potash, of which 92.27 per cent. has been removed. Soda has lost about 75 per cent., magnesia, 49 per cent., lime 45 per cent., silica, 27 per cent., and iron oxide less than 4 per cent.

The process of weathering has involved this considerable solution, together with oxidation and hydration. The accompanying physical changes are a complete change of color, and a disintegration so thorough that the material may be easily scooped out with the hands.

The contrast between alteration and weathering is pronounced. The former led to the formation of serpentine and calcite, without oxidation. Weathering, on the other hand, destroyed both of these minerals and effected much oxidation. The first process could hardly be regarded as destructive, the last is eminently so.

The weathered dike occurs in the nearly vertical rock wall of the creek gorge, which is doubtless of postglacial origin. As the dike, in its present condition, would offer almost no resistance to the attack of the stream, it is evident that in the first stages of gorge cutting the rock must have been nearly or quite unweathered. From this it follows that the weathering, as now seen, has been accomplished in postglacial time.

THE

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A SYMPOSIUM ON THE CLASSIFICATION AND NOMENCLATURE OF GEOLOGIC TIME-DIVISIONS.

THE infelicities which arise from the uncertain use of terms in the discussion of geologic time-divisions are more or less fully appreciated by every working geologist. The peculiar difficulties which the varying and often inconsistent use of terms imposes upon the student of geology when he leaves the narrow confines of his text-book and tries to use the current literature of the science, can only be realized by those teachers who have encouraged this broader method of study and conscientiously feel responsible for the results. Not every text-book, even, is consistent with itself. It is too much to insist that it should be consistent with general usage until a consistent general usage is established. The importance of a more systematic classification of time-divisions and rock-series has been recognized by the international congresses of the last two decades. The limited results that have been reached by the efforts of these congresses seem to indicate that the problem must be worked out by gradual approaches through tentative efforts. It perhaps also indicates that the problem must be in large part worked out in the great provinces or in the individual continents separately as a preliminary to intercontinental coördination. Not a few geologists who heartily sympathize with the effort to secure more uniform and better practice are yet quite unwilling to have a rigid system imposed by the vote of a body of so uncertain composition as an international congress. Quite aside from doubts connected with such an enacting body, there are those who question whether we have reached that stage in the development of interpretations and correlations which warrants the formal adoption of a universal system of classification and nomenclature. Fully sympathizing with both these classes, we none the less feel that these considerations only emphasize the importance of those preliminary and tentative efforts through whose agency a satisfactory system is to be worked out in time by the method of concerted trial and continued rectification. Especially does it seem important to proceed as fast as may be with the evolution of a system appropriate to our own continent as a preliminary to the establishment of an intercontinental system.

Certain phases of a system of nomenclature involve little more than a choice of terms. To this extent only a consensus of preference is needed to inaugurate a common practice which shall become conventional. In most cases, however, the choice of terms is connected with a choice of ideas, and a consensus is less readily reached. Whether a community of preference can now be reached or not, it can scarcely be questioned that we should work toward such a community, if possible, rather than away from it. We appear to have been receding from uniformity, rather than approaching it, for the past two decades. The result is a disturbed practice and a confusion of terms infelicitous alike to geologist, to teacher, and to student.

The more important phase of the question lies back of the selection of terms and relates to the questions: What divisions, or what order of divisions, shall be chosen for formal nomenclature, and upon what criteria shall the divisions be determined? Granting that these questions cannot be answered finally at present, or in the near future, it is still urgent to inquire: By the use of what system, provisionally adopted for current use, can we best work on toward better systems in the future?

To draw out opinion on the subject, a series of questions was prepared by one of the editors of this Journal (Professor Salisbury) and submitted to several American geologists with a view to inaugurating discussion. The questions were made specific to invite definiteness in the replies. They were made to overlap somewhat to facilitate specific answers to different aspects of the subject. It was not intended to specifically advocate the scheme presented, but merely to submit a tangible sketch for discussion. A portion of the replies are printed in this number. The discussion of the subject by others who may be interested is invited. The questions submitted are as follows:

1. What classification of time (and terranes), say to the third or fourth division, seems to you best adapted to North America? If you are ready to express your opinion concerning such a classification to the second division, but not farther, please do so.

2. To what extent is it desirable to adhere to European standards, if some other classification is better adapted to North America?

3. What noun should be used in connection with the adjectives *Palæozoic*, *Mesozoic*, etc., 1° when time is meant, and 2° when formations are concerned? For example, Palæozoic *era?* Palæozoic *group?*

4. What noun should be used in connection with the primary subdivisions of the Palæozoic such as Cambrian, 1° when time is meant, and 2° when formations are concerned? For example, Cambrian *period?* Cambrian *system?*

5. What is the best noun to be used in connection with divisions of the third order, such as Lower Cambrian, Middle Cambrian, etc.? For example, Lower Cambrian *epoch?* Lower Cambrian *formation?*

6. Ditto for divisions of the fourth order.

7. Would you approve of the separation of the sub-Carboniferous and the Permian as divisions coördinate with the Carboniferous proper, the Devonian, etc.

8. If you approve of the separation of the sub-Carboniferous from the Carboniferous, as a division of the second order, would you approve of retaining the name sub-Carboniferous or Lower Carboniferous, or would a new name be better, say Mississip-

pian? The repetition of terms involved, if the term sub-Carboniferous or Lower Carboniferous and Carboniferous continue to be used as now, is so great as to be very confusing to students. Those who have not dealt with students beginning the study of historical geology may not be aware of the difficulty involved in such a system as the following:

Carboniferous,
  Permian,
  Carboniferous,
  Sub-Carboniferous.

9. Would you approve of the separation of the Cretaceous into two divisions coördinate with each other, and each coördinate with such divisions as the Devonian?

10. If so, would you approve of the retention of the names Lower Cretaceous and Upper Cretaceous, or should one of these divisions, presumably the Lower, receive a new name, say Comanche?

11. How should the Cenozoic be subdivided?

12. What is the advantage of the term *Canadian*, and the corresponding *Trenton*, in the following classification?

Ordovician	Trenton	Hudson River Utica Trenton
	Canadian	Chazy Calciferous

Why not instead?

Ordovician	Hudson River Utica Trenton Chazy Calciferous

13. Will you express your opinion concerning the following outline where the divisions are carried to the second order?

Era (for time) Group (for rocks)	Period (for time) System (for rocks)
Cenozoic	Pleistocene Pliocene Miocene Eocene

Mesozoic - -	Cretaceous (Upper) Comanche (Lower Cretaceous) Jurassic Triassic
Palæozoic - -	Permian Carboniferous Mississippian (sub-Carboniferous) Devonian Silurian Ordovician Cambrian
Proterozoic - -	Keweenawan Upper Huronian Lower Huronian
Azoic - -	Archæan

14. What would you say to this plan of classification:

Era - - -	Group
Period - - -	System
Epoch - - -	Series
Stage - - -	Formation

CONTRIBUTION BY JOSEPH LE CONTE.

I hereby give answers to your questions as briefly as possible:

1. I am not prepared to go further than divisions of the second order.

2. European standards, as first in the field, must be followed as far as possible, but should be modified, if necessary. But eventually we must have a world standard, at least for divisions of first and second orders.

3. I think—Era and Group are best.

4. " " Period and System are best.

5. " " Epoch and Series are best.

6. " " Stage and Formation are best.

7. (*a*) *Sub-Carboniferous* is certainly coördinate with Carboniferous proper, but I do not think that *Permian* is. Witness the tendency to unite Carboniferous and Permian under Permo-Carboniferous.

(*b*) But I much doubt that these are coördinate with *Devonian.*

8. "Mississippian" serves our American purposes well, but, if used, ought to be coupled with Lower Carboniferous as synonym, as you have done.

9. Cretaceous ought to be divided into two coördinate divisions, but I do not think these are at all coördinate with Triassic, Jurassic, or Devonian. They must be regarded as sub-periods.

10. I think it best, therefore, to retain the names Lower and Upper Cretaceous; but, if a new name is used for the lower division, why not call it "*Shasta.*" It was certainly first recognized there.

11. I am in favor of the fourfold division of Cenozoic you propose, although I fully appreciate the reasons for uniting Miocene and Pliocene into Neocene. Tertiary and Quaternary might well be abolished, as Primary and Secondary have already been.

12. I see no sufficient reason for the names Canadian and Trenton as sub-periods. Better divide Ordovician at once into epochs, as you suggest.

13. I like your schedule of divisions of first and second orders except as regards the Cretaceous and Carboniferous, as already explained. Also, I do not like the term "Azoic," although not prepared to suggest anything better.

14. I fully endorse your general plan of classification for time and strata. JOSEPH LE CONTE.

CONTRIBUTION BY G. K. GILBERT.

So long as historical geology continues to be a living science no definite system of nomenclature can hope to be permanent, nor even, perhaps, to give temporary satisfaction to a majority of geologists. Nevertheless, as intimated by the JOURNAL's circular letter, teachers and geological surveys must have definite systems, and so the task of making and remaking them is a sort of necessary evil.

(Questions 1 and 2.) Though time is universal, faunas and histories are more or less local. A refined time scale cannot be used to advantage in the correlation of formations widely separated. Therefore, only the major orders of a time classification should be treated as universal, and the minor should be recognized as local. I suggest that the line of discrimination be arbitrarily drawn between divisions of the second and third ranks, periods and epochs.

Pursuant to this suggestion, I propose the following auxiliary criterion for periods (not replacing but supplementing other criteria): Periods should have such magnitude that their application to the correlation of formations anywhere in the northern hemisphere will yield areas of certainty which are large as compared to the unavoidable zones of doubt.

This criterion is used in the selection of the subjoined scheme of periods, but is subordinated to other considerations in the admission of Pleistocene and Algonkian. Jurassic and Triassic are given separate place despite their broad zones of doubt when applied to American terranes, because the breadth of those zones is due to dearth of the most important data for correlation, marine fossils.

Periods.

12. Pleistocene (or Quaternary).	6. Devonian.
11. Tertiary.	5. Silurian.
10. Cretaceous.	4. Ordovician.
9. Jurassic (or Jura).	3. Cambrian.
8. Triassic (or Trias).	2. Algonkian.
7. Carboniferous.	1. Archæan.

(3.) Four time-nouns have been used in this rank by various authors: *Era*, *age*, *eon*, and *time*. *Time* cannot be spared from its general sense. Of the others *eon* alone has a good connotation for this place; its untechnical meaning always includes long duration.

Group is not well placed in this rank. Prevalent American usage, which puts it next above the unit *formation*, is in harmony with the ordinary meaning of the word,—an aggregate of individuals (not an aggregate of aggregates).

(7.) No.

(7, 8.) I like Mississippian as the title of an American subdivision of the Carboniferous period. There is need of a complementary, coördinate, American, geographic name (or names).

(9.) No.

(14.) I prefer:

Eon - - -	System (or Series).
Period - - -	Series (or System).
Epoch - - -	Group.
Stage (or Age) -	Formation.

(Comment on 5, 8, 10, 13.) The adjectives of space relation, *Lower* and *Upper*, should not appear in a time scheme. The prefixes *Eo-*, *Meso-* and *Neo-* (proposed for a somewhat different use by Williams) seem appropriate for the indication of indefinite portions of any time unit. For definite parts separate geographic names are preferable. G. K. GILBERT.

CONTRIBUTION BY WM. BULLOCK CLARK.

I think that the questions, which you have raised regarding the use of terms in geological classification, are most timely. If a discussion of the subject can aid in bringing about some unanimity in the employment of these terms on the part of geologists, you will have performed a great service.

I am inclined to take the position that, from the very nature of the case, a universal system of stratigraphic equivalents cannot be employed for the chronologic terms. The chronologic divisions, as we all recognize, are at best highly artificial, while the stratigraphic divisions are natural and definitely determinable units. The term "formation," for example, has come to be rather widely used to embrace deposits formed under approximately similar conditions whatever the time element involved, and may or may not be separated from overlying or underlying formations by an unconformity.

Accepting the chronologic terms which you have adopted, and which, I think, cannot be improved upon, certainly to the third division—viz., era, period, epoch—it may be possible to find the formation as the equivalent of a portion or the whole of any one of these time divisions, excepting, perhaps, the era. To attempt to restrict it, therefore, in all instances to any chronologic division, large or small, would seem to me unwise.

Furthermore, I think that a different series of names should be applied to the formations and their subdivisions than to the time units. I should speak of the Palæozoic era or time, the Cambrian period, and the Upper Cambrian, or better, the Neo-Cambrian epoch, but of the Potsdam formation or the Shenandoah formation, the latter representing portions of the Lower Silurian as well as Upper Cambrian, and affording a good example of the formational unit. I prefer the prefixes Eo-, Meso- and Neo- to designate the epochs, as proposed by Williams. I think the term Stage more applicable to a division of a formation, whether characterized by a distinct fauna or not, than to a time unit.

In reply to your questions seven and eight regarding the later divisions of the Palæozoic, I should employ the chronologic terms Carboniferous and Permian, the former divided into Upper and Lower, or Upper, Middle and Lower Carboniferous, as the case might be. To be consistent the terms Eo-, Meso- and Neo-Carboniferous should be used. The Upper Carboniferous may be represented by Coal Measures made up of one or more formations; the Lower Carboniferous may be represented as in the central United States, by the Mississippian, or, as I should prefer, the Mississippi Group, made up of various formations. I should personally object to the use of the term Mississippian in a chronologic sense, unless the period term Carboniferous was to be permanently divided and the resultant divisions raised to the period rank. The reasons for such change, however, do not seem to me to be sufficiently strong. I think the widely extended difference in facies represented in the Upper and Lower Carboniferous tends greatly to accentuate the two divisions of this period.

These same reasons seem to me to apply equally well to the Cretaceous. Although there is a very considerable difference between the upper and lower divisions, it does not seem to me sufficiently great to warrant their elevation to equal rank with Devonian, Carboniferous, etc. I should, therefore, employ Comanche in its original sense as a stratigraphic term, and, as several formations are clearly recognized within the limits assigned to it, I should be inclined to speak of the Comanche Group.

I should prefer to divide the Cenozoic into Eocene, Neocene, and Pleistocene as the most widely recognizable time units, placing under the earlier term Eocene the subsequently named division Oligocene of von Beyrich and uniting Miocene and Pliocene into Neocene.

I can see little advantage in the use of the terms Canadian and Trenton, except as group names, to include the Calciferous and other formational divisions.

I prefer the use of Lower Silurian to Ordovician, as I do not think the term Silurian of Murchison can with propriety be restricted to the Upper Silurian. If the Upper and Lower Silurian are to be raised to period position, and Ordovician used, I think some other name should be substituted for Silurian.

Wm. Bullock Clark.

CONTRIBUTION BY S. W. WILLISTON.

I am greatly pleased with your attempt to reduce some kind of order out of the chaos that has been made in geological nomenclature. I think no one but the actual teacher of historical geology can appreciate the amount of confusion that now exists and the vexation that it causes both teacher and pupil.

To the first five questions I am not prepared to offer suggestions except this, that it will make very little difference what terms are used for the time and formation, provided there is uniformity. I am ready to accept and teach any system that receives the approval of writers on these subjects, and is used with tolerable fixity and uniformity.

7. To this proposition I would desire to enter a vigorous protest. Having worked in Kansas, where the Permian is best represented in this country, I can see no good grounds whatever for distinguishing between two groups in respect to which neither the palæontologist nor the stratigraphist can determine where the one begins and the other ends. Palæontologically there is nothing of sufficient importance to warrant the division into primary periods. It is true that, so far as we now know, the reptiles began in this time, but every palæontologist confidently expects that they will be found in the true Carboniferous, and in fact they have been found in Kansas in strata that are yet in dispute. Knowing less of the sub-Carboniferous, I cannot give an opinion here, but I do not believe there are any better grounds for division than between the Carboniferous and the Permian.

Classification of the time periods of the earth must inevitably follow the same rules as those applied in the classification of animals and plants, which in the end becomes one of convenience, chiefly. If we increase the number of primary divisions, as the tendency seems to be, the number will at last become so large that some future classifier will insist upon reuniting many of them under new and undesirable names. The chief divisions should represent, so far as possible, time periods of equivalent importance, and to say that the Permian period is an equivalent of the Carboniferous, or the Silurian, is certainly incorrect. Personally, I would rather see the Trias annexed to the contiguous divisions!

8. I should much prefer to see the name Carboniferous applied to the primary division and distinctive names given to the three subdivisions. There is a *very* great, almost intolerable, objection to using the name Carboniferous in two senses, or even the Carbonic and Carboniferous. I very much hope that the name Mississippian may be given to the lowest group, some good distinctive term to the intermediate, as Coal Measures, and Permian applied to the uppermost.

9. For many of the same reasons already given for the

Permian, I strenuously object to the subdivision of the Cretaceous into two primary divisions. Certainly, so far as vertebrate palæontology is concerned, there is no good reason for the division, and there are many opposed to it. I would rather prefer Upper and Lower, for the divisions of the Cretaceous, but would willingly see such terms as Platte and Comanche used.

11. I would prefer to have the Cenozoic divided into the Eocene, Miocene, Pliocene and Pleistocene. I believe this is the only logical system, unless, perhaps, the Oligocene is added. Nevertheless, I see great difficulty in superseding the much used Tertiary. Most assuredly there should be no distinction into "Tertiary" and "Quaternary," and, if Tertiary is used, its limitations must be widened to include the Pleistocene. This will be equally hard to do, and for that reason I believe, upon the whole, the best way is to drop the term Tertiary entirely.

14. I am quite ready to use the plan of classification given in my teaching and writings, if its use can become at all general. Fixity and uniformity are all that I ask for here.

13. The terms and divisions that I think ought to be adopted, so far as I have grounds to base my opinions upon, are as follows:

Cenozoic, - - -	Pleistocene,	
	Pliocene,	
	Miocene,	
	Eocene,	
Mesozoic, - -	Cretaceous,	Upper. Lower.
	Jurassic.	
	Triassic.	
Palæozoic, - - -	Carboniferous,	Permian. Coal Measures. Mississippian.
	Devonian,	
	Silurian,	
	Ordovician,	
	Cambrian.	
Eozoic or Proterozoic,		
Azoic.		

I have done very little field or laboratory work upon the divisions prior to the Carboniferous and refrain from expressing an opinion about them.

I very much prefer the use of European terms for divisions that can be correlated with tolerable exactness; otherwise distinctive American terms should be used.

I sincerely hope that you will bring some order out of what has been so confusing to both teacher and student.

S. W. WILLISTON.

CONTRIBUTION BY BAILEY WILLIS.

Your inquiries of May 5, concerning the use of certain common terms in geology and questions of classification, were duly received and have been carefully considered. In answering I beg to state that I express my personal opinion as determined by experience in practical field work and in editorial work on geologic maps.

The following answers are arranged categorically, according to the numbers of the questions to which they refer.

1. *Eras, Systems.* — Terms to be applied respectively to the grand divisions of time and the rocks representing them, as determined by the most important events of biologic development.

Periods, Groups.— Arbitrary divisions respectively of time and rocks within the eras and systems, designed to afford means of approximate designation of the position of any geologic record in the time scale. These should be applied consistently the world over according to the volume of stratigraphic evidence as checked by palæontology, but it does not necessarily follow that in North America they designate time divisions precisely contemporaneous with those distinguished in other continents.

Ages, Series. — Terms to be applied respectively to subdivisions of time and rocks less than period and group, but including a consistent sequence of biologic or lithologic changes without break. An age or series may include parts of two periods or groups.

Epochs, Formations. —Terms applied to designate the time represented by the lithologic unit which may be mapped on a given scale and the lithologic unit itself.

Episodes for time, Lenses and Lentils or Stages for rocks.— Terms applied to local lithologic variations or limited rock masses which for purposes of discussion need to be defined, but are not of sufficient consequence to justify the distinction of a separate name.

I may briefly state my reasons for the above suggestions as follows: (1) I associate era and system because the classification is based on the broadest natural facts and is therefore systematic. (2) I associate group with period because both terms appear to me less precise and adapted to the arbitrary character of the unit thus classified. The division of time according to a scale of periods appears to me equivalent to the division of a column of mercury according to a scale of degrees to indicate temperature; whether the result be expressed in the arbitrary terms of Fahrenheit or Centigrade the fact remains unmodified. The simplest scale which will satisfy the needs of world-wide geology is to be preferred. (3) I associate age and series as both of them indicate a consistent logical sequence of events having their beginning and rounding out to an end, as in history we have the Elizabethan age and the series of events which characterize it. Age and series are natural divisions as distinguished from period and group, which are terms of the arbitrary scale. (4) I associate epoch and formation probably rather through custom than for any special reason, but I prefer epoch as a time designation to stage because the latter has a more concrete significance and might with equal aptness be applied to a subdivision of rocks. Indeed, if a geologist named to me the Medina stage, I should understand that the sandstone was referred to rather than the time for which the sandstone stands. Furthermore a stage appears to me to represent a temporary or very brief condition and to correspond in time with the term episode. The necessity for the fifth subdivision, corresponding to episode, frequently arises in detailed discussion, and is a means of avoiding complexity of nomenclature. Thus if a conglomerate lens appears in the Medina formation it can be referred to as the Medina conglomerate lens or episode, without burdening the discussion with a new name, which the conglomerate should receive if it be considered a formation.

2. To that extent which promotes unity of classification without contradiction of fact and no further. In case of doubt whether European standards apply to North American facts, it is better to adopt a North American standard in accordance with the facts.

3. Palæozoic era, Palæozoic system.

4. Cambrian period, Cambrian group.

5. Lower Cambrian age, Lower Cambrian series.

6. Medina epoch, Medina formation.

7. No. The multiplication of period divisions does not in my judgment tend to the advantage of geologic students.

8. The absurdity of a double meaning for any term is apparent. The usage arises from the effort at excessive subdivision in terms of periods.

9. and 10. No. This question has been several times considered, and the requirements of the case are adequately met by the use of the terms Comanche age and Comanche series.

11. Pleistocene, Neocene, Eocene.

12. I should omit Trenton and Canadian as superfluous.

13. The proposed scheme contains an undesirable number of period divisions. The sets of facts and corresponding times represented in the scheme by Pliocene, Miocene Comanche, Jurassic, Triassic, Permian, Mississippian, and Ordovician I should transfer from the list of periods to that of ages, where I think they would be adequately represented.

14. Answered under 1. BAILEY WILLIS.

CONTRIBUTION BY C. R. KEYES.

If I understand the questions rightly it would seem more logical to attempt to answer the last one first.

Uniformity of terminology is the great desideratum of working geologists. The main drawback to the adoption of any proposed scheme appears to lie in the disinclination of most writers to make any distinction between a technical and common usage of words. Terms that already have assumed special meanings should be used only in a technical sense. For expressing ideas in which a restricted meaning is not implied there are many common terms.

In geological classification a dual scheme has come to be so universally recognized that it is difficult to imagine that any other is possible. Yet, for local successions of strata a single set of adjectives suffices to designate both the subdivisions of time and those of substance. Hence, with five orders of terms to denote the taxonomic rank of the name used—and these appear to be all that will ever be useful in practical work—we have:

Order.	For Time.	For Rocks.	Example.
1.	Era	Assemblage.	Palæozoic
2.	Period.	System.	Carboniferous.
3.	Epoch.	Series.	Mississippian.
4.	Episode.	Stage.	Kaskaskia.
5.	Hemera.	Zone.	Pentremites Godonii.

The word group, sometimes used for the largest rock division, is so thoroughly incorporated in our literature in a different sense, and is generally so loosely applied, that it seems hopeless, and in fact very undesirable, to attempt to give it, at this late day, a technical meaning. Moreover, it is far more useful now, with its present indefinite application to any selected number of beds or subdivisions, than it could possibly be in a more restricted sense. Some other title should take its place for technical purposes. It makes little difference what it is. Its general adoption is the most important feature. Assemblage, the name here given, is merely suggestive. It is somewhat ponderous, but is expressive of the grand subdivisions.

Stage is a word associated not with the idea of time, but of place. It is, therefore, more properly applicable to the fourth structural order, interchangeable, perhaps, with formation. But the latter term may be extended without confusion to crystalline masses also. As the stages are based largely upon lithological characters and receive local geographic names, the latter are followed by such words as limestone, shale, granite, etc., thus doing away with the technical title altogether. In general the word formation seems to be best retained for use in somewhat doubtful cases, where the exact taxonomic rank is questionable, but believed to be about of the fourth order; while group refers to any of the greater orders.

The time equivalent of the stage seems best expressed by the word episode. The word Time is also appropriate, and it more exactly corresponds with the historical usage to represent a generation.

The zone is a useful subdivision of the smallest unit usually recognized in this country, The name of its time equivalent is Hemera, proposed by Buckland. The zonal classification of the Ammonite-bearing beds of the Jurassic is an example.

Assuming the ultimate aim of every scheme of geological chronology to be to provide a means of paralleling stratigraphic successions more or less widely separated geographically, a practical question arises as to how far a general classification is applicable to a given region, and how far the local plan is capable of being expanded.

While the double geological scale is theoretically everywhere balanced, in practice the time element is given precedence at the more general end of the scheme, and the rock element at the more specific or local extremity. In the present state of our knowledge general correlation farther than series is beset by many and grave difficulties, and it is doubtful whether it is feasible to extend it beyond.

So far as concerns the first two orders enumerated in the plan already given, it seems desirable, for the present, to retain the names generally applied to the different "groups," even though they are largely European in origin and are not exactly expressive of the real conditions in North America. They are so thoroughly part and parcel of our literature that it would be revolutionary to supplant them. It is better to modify their meanings somewhat, rather than discard them altogether. Besides they have entirely lost their local original significance. They are now abstract terms. In this country the data will soon be at hand for the construction of an entirely new chronological plan, having a purely physical basis, the biological criteria being ignored altogether.

In the third order there is an overlapping of general and local criteria. To express the time factor the words Early, Mid- or Middle, and Late appear appropriate; as Early Cretaceous. The simple Anglo-Saxon names are much more preferable than the long barbarisms, produced by the Greek prefixes Eo, Meso and Neo. Simplicity of terminology should be a cardinal principle if geological science is ever to receive the popular attention it deserves. For the rock scale, Lower, Median or Middle, and Upper are useful terms to indicate in a general way the corresponding subdivisions; as Lower Cambrian, Lower Carboniferous. Or, the latter titles may be used in a somewhat indefinite way, when the exact stratigraphic limits are yet unknown.

Here the local succession begins to assume importance and the general time factor to lose it. Each geological province has its own sequence of strata. A provincial geographic name is desirable, if possible with an adjective ending. Thus, we have for the Lower Carboniferous in the Mississippi province, the Mississippian series; in the Appalachian province the Poconon series, possibly; in the Great Basin province the Aubreyan series, perhaps. The number of series is thus not fixed for any system, as locally represented, nor for different localities. Yet the epoch of all is definite. The time may come when it is desirable to have some special name to cover all the provincial series of approximately the same age, but the condition of our knowledge does not yet warrant it. It is doubtful whether it would be any improvement on the simple Lower, Middle and Upper.

An ideal feature of geological nomenclature is uniformity of endings for all terms of equal taxonomic rank. With those of the first order this method already prevails. In the case of those of the second order a variety of different terminations exist; but it is probably not advisable now to change them. However, these names are so few in number that they are not liable to cause confusion. The provincial titles of the third order are in large part yet to be proposed. For all these an appropriate original or provincial name is suggested, with the ending *an*, if possible. This leaves the countless horde of formations, or stages, the usual units of geological mapping, the distinguishing characters of which are based chiefly upon lithology, a clear field for unchanged, local, geographic honors. The zones are named from their leading fossils.

Our information regarding the geological subdivisions is so unequally distributed that at best a very unsymmetrical classification must be endured for the present. The following seems to be the most acceptable scheme for North America:

Era.	Period.	Epoch.	
Cenozoic.	Pleistocene.	Late or Recent.	
	Neocene.	Early.	
	Eocene		
Mesozoic.	Cretaceous.		
	——— ?		
	——— ?		
Palæozoic.		Late	For all.
	Carboniferous.	Mid.	
	Devonian.	Early.	
	Silurian.		
	Ordovician.		
	Cambrian.		
Proterozoic	Keweenawan		
	Huronian?		
	Laurentian ? or new name.		
Azoic	Archæan.		

For purposes of instruction the provincial scheme for rocks for the special region studied may serve as a standard.

It is desirable to adhere to European standards, or the present American standards as derived from Europe, as closely as possible until our present knowledge expands sufficiently to enable us to gradually erect new and more rational standards. The first and second orders should be as closely equivalent as possible, and with the same names for both continents, and for the whole world. It is better to have everywhere the same terminology with approximate parallelism in meaning than different names and no means of unconscious comparison.

At the present time no series are formally recognized in the Devonian. The system is doubtless as well differentiated in this respect as the Carboniferous.

It is exceedingly doubtful whether the term Permian should be permitted to hold a place in American geological literature or classification. The original Permian is perhaps applied to a provincial series, taxonomically of the same rank as Mississippian. In America the so-called Permian is also a series and actually a subdivision of the Carboniferous. The same is true of the so-called sub-Carboniferous. It follows that neither should be coördinated with the Devonian.

The use of the term sub-Carboniferous in American geology is very unfortunate. As originally proposed, and as used for a long time afterwards, it referred to an indefinite sequence of strata extending downward from the "Coal Measures" even as far as the Trenton. As more recently used the subdivision so called would be better designated the Lower Carboniferous, the serial rank being understood, Mississippian being regarded as the equivalent provincial title as explained above. Neither Carboniferous nor any other unqualified term should be used for both system and series, or any two subdivisions of different taxonomic rank.

Canadian seems wholly out of place in the sense used unless it can be modified so as to denote a series. The use of Trenton in two different senses should be discontinued. It appears unnecessary to retain the word river in connection with Hudson — even though it has been widely used. And similar double geographic names are to be avoided.

CONTRIBUTION OF SAMUEL CALVIN.

Referring to your inquiries relative to the classification of time and terranes best adapted to North American geology, I would say that I am disposed to be very conservative and would like to see as little disturbance as possible of terms that have met with somewhat general acceptance. The terms, *Group*, *System*, *Series*, *Stage*, and the correlative time-divisions, *Era*, *Period*, *Epoch*, *Age*, are to my mind very satisfactory. Of course any other terms would answer equally well provided geologists were agreed to use them. What we need to do, as it seems to me, is to adopt in this case the method that is in most general use, and by extending the use of it to make it more and more general until it becomes universally adopted. I would not like to see the term *Formation* used in place of *Stage*, and this simply for the reason that *Formation* is now in use as a loose, general term. Such a term is very much needed, and any attempt to change *Formation* from a loose to a precise term would be attended with great confusion. Heaven knows we have confusion enough now to contend with.

It does not seem to me to do any harm to leave the Lower Carboniferous or Mississippian as a division of the Carboniferous. The use of the term Mississippian would be an advantage ; and the arrangement I would prefer, simply as a result of my attitude of conservatism, would give Mississippian the same rank as Corniferous, Hamilton and Chemung in the stratigraphy of the Devonian.

The greater part of the assemblage of strata called Permian by Prosser and the geologists of Kansas University contains precisely the same fauna as our Missourian or Upper Coal Measures, and if there is no better excuse for recognizing Permian in America than that afforded by the beds in question, then America has no Permian. At all events if these strata are Permian then the Permian cannot be separated from the Carboniferous. A large percentage of the so-called Permian fauna occurs in the coal-bearing strata of Indiana, Illinois and Iowa, that is, the fauna actually begins in what we call in Iowa the Des Moines stage, or Lower Coal Measures. Personally I see no good reason for recognizing Permian in America, but if we must in order to keep up with Europe, then the Permian must rank as a subdivision of the Carboniferous. We might therefore arrange the Carboniferous in some such way as this :

Carboniferous	Permian.	
	Pennsylvanian or Coal Measures	Missourian.
		Des Moines.
	Mississippian or Lower Carboniferous	Kaskaskia.
		Saint Louis.
		Osage or Augusta.
		Kinderhook.

9. I would prefer to leave the Cretaceous undivided, being governed in this choice simply by the conservative desire to leave things undisturbed. The literature of the Mesozoic is based on the division into the Triassic, Jurassic and Cretaceous, and any change will require a long period of adjustment and will involve endless confusion. It is much easier, and just as convenient to let the Cretaceous stand as a single system and divide it into a Lower (Comanche ?) and an Upper (unnamed) series.

Cretaceous System	Upper Cretaceous (Black Hills series)	Denver.	
		Laramie.	
		Montana.	
		Colorado.	
		Dakota.	
	Lower Cretaceous (Comanche series)	Washita	or any other arrangement.
		Fredericksburg	
		Trinity	

The whole of the Upper Cretaceous, excepting the Laramie and Denver, is well developed around the flanks of the Black Hills.

We can retain the established names in the Cenozoic and adapt our nomenclature with perfect ease to the old arrangement by adopting appropriate stage names. We shall here need two sets of stage names, one for the marine Tertiary and the other for the fresh-water Tertiary deposits.

Cenozoic Group	Pleistocene	Recent.
		Glacial.
	Tertiary	Pliocene.
		Miocene.
		Eocene.

12. There is some advantage in retaining the terms Canadian and Trenton as names of series in the Ordovician. The faunas of the Trenton limestone, the Utica and Hudson River shales are very intimately related, and that relation should be indicated by grouping the three together as stages of a single series. The Calciferous and Chazy should similarly be grouped into one series.

I believe if you have patience to read all this that you will see how I would stand with reference to the several questions in your circular letter. Any classification is arbitrary at best. A dozen or more equally good schemes might be proposed, but we should adopt and strengthen as far as possible that which is in most general use, notwithstanding the fact that it might be improved in many respects. SAMUEL CALVIN.

PROBABLE STRATIGRAPHICAL EQUIVALENTS OF THE COAL MEASURES OF ARKANSAS.

One of the most striking features connected with the coal field of the western interior basin is the enormous thickness which the productive Coal Measures appear to attain in the southern part of the area as compared with the northern and larger portion. From the Minnesota line, southward through Iowa and Missouri, to northwestern Arkansas — a distance of more than 500 miles — the principal coal-bearing series retains a thickness of not more than 500 to 600 feet. Cretaceous and Tertiary beveling and planing, as well as later erosion, have of course thinned out the beds to a feather-edge towards the east. Passing into Arkansas the formation rapidly becomes thicker until it has a vertical measurement of more than thrice that to the north. According to Branner's[1] latest estimate the "Coal Measures" of that region are over 2400 feet thick.

In the various comments upon this great thickness which the Carboniferous rocks above the Mississippian series at once assume on passing to the south side of the Boston mountains, into the Arkansas valley, no hint has been given as to the probable conditions that produced such a remarkable phenomenon.

One thing that has tended to greatly obscure the real facts has been the assumption that the old Algonkian and old Cambrian or Silurian areas of the Ozark region formed, during all Palæozoic times, a large island in the shallow continental sea. The evidence, as recently set forth, seems indisputable that not only did no "Ozark Isle" exist during late Palæozoic time, but that the present dome-shaped, island-like character of the region, with the central old rocks, and the concentric belts of newer deposits around, was not acquired until Tertiary times. Furthermore, there is every reason to believe that the Carboniferous

[1] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

strata once extended unbrokenly over the whole area now occupied by the uplift, and that they were removed through erosion.

As already remarked the great thickening of the Coal Measures begins to make itself apparent immediately south of the Boston mountains; north of this range the stratigraphy has been more or less clearly understood. The two main subdivisions are clearly defined over all of the northern region. There they represent a lower, or coastal facies and an upper, or marine phase. The plane separating them is the base of the first thick limestone above the Mississippian series. This formation is now called the Bethany limestone. It is a marked and persistent feature of surface relief from north-central Iowa, where it emerges from beneath the Cretaceous, southward through northwestern Missouri, and southeastern Kansas, to the Indian Territory line, beyond which it has not been traced in detail, although at that point it still continues to be an important and easily recognizable ridge.[1]

Regarding the southern part of the coal field much has been written, but it has only been very lately that definite data have been given, that enables comparisons with the northern districts to be made. The facts recently published have a special importance at this time for the reason that they strongly support certain views concerning the physical conditions, the existence of which have been, for some time, suspected, and enable several statements to be formulated regarding the character of Carboniferous deposition in the region. The data particularly referred to are contained in a paper by J. P. Smith[2] on the "Marine Fossils from the Coal Measures of Arkansas." While the facts therein presented are not nearly as complete as is to be desired, they nevertheless appear sufficient, when taken in connection with information derived from other sources, to permit several pregnant deductions to be made.

One of the most noticeable features of the Carboniferous

[1] Am. Jour. Sci., (4), Vol. II, pp. 222–225, 1896.

[2] Proc. American Philos. Soc., Vol. XXXV, pp. 213–285, 1896.

deposits of Arkansas, and especially those of the western part of the state, is the prevalence of sandstones and shales above the strata of the Augusta stage (Boone chert) of the Mississippian. There are, however, in the region occupied by the Boston mountains, two limestones of unusual thickness which lie at levels considerably above the Augusta beds. These have been called[1] the Archimedes and Pentremital limestones. They are separated from each other by 40 to 75 feet of shale. The interval between the first mentioned and the limestones beneath is about 200 feet and is occupied by shales and sandstones. The Pentremital limestone may be taken, with but little doubt, as corresponding to the Kaskaskia limestone of western Illinois. Its stratigraphical, lithological and faunal characters all agree in this respect.[2] There do not appear to be any indications of a plane of unconformity at the top of this heavy Pentremital formation, as there is at the summit of an equivalent stratum along the Mississippi River. The Arkansas sequence of the Carboniferous seems unbroken and undisturbed from base to top. The Pentremital limestone may be therefore regarded as the uppermost member of the Mississippian of the region, and the overlying coal-bearing shales as the basal portion of the Coal Measures, or Des Moines series, of the more northern localities.

In regard to the upper limits of the Arkansas valley Coal Measures, or of any definitely determinable horizon in the great succession, there are not yet at hand any very critical data. The lately issued notes of Smith[3] on the fossils collected in the region by the members of the Arkansas Geological Survey give the first tangible facts that have been obtained, and by which any comparison whatever can be made with the better known region north of the Boston mountains.

All who have worked in the Arkansas valley agree in assigning a very great thickness to the Coal Measures of that region. This is readily inferred from the writings of Chance,[4]

[1] SIMONDS, Arkansas Geol. Surv., Ann. Rept. 1888, Vol. II, p. 26, 1891.

[2] American Geologist, Vol. XVI, pp. 86–91, 1895.

[3] Loc. cit.

[4] Trans. American Inst. Min. Eng., Vol. XVIII, pp. 653–661, 1890.

Winslow,[1] Stevenson,[2] Branner[3] and others. While the total thickness of the Coal Measures is doubtless somewhat overestimated by these authors, it is manifest that the formation is very thick—several times as great as it is farther northward.

The subdivisions of the Arkansas Coal Measures that have been recognized have not always been the same. In several instances they have been quite different. The classifications have been either noncommittal as to exact correlation with other regions, or they have been very general. The members distinguished have been largely for convenience in local field work. The tendency has been, however, to regard the Coal Measures of this region as about equivalent to the Coal Measures ("upper and lower divisions") of other districts north and east, with the intimation, in the later notes, that the so-called Permian of the western part of the Mississippi basin, may be present to some extent, as for example on Poteau mountain. In the latest contribution to the subject by Smith,[4] the "Upper Coal Measures" and the " Lower Coal Measures " of the Arkansas valley are paralleled with the similarly named formations of the Missouri region. The Poteau mountain beds are included. The conclusion is that "there is not sufficient reason for classing the Poteau mountain beds with the Permian, but their fauna, as well as stratigraphic position, place them very high in the Coal Measures, since they are like the fauna and position of the Mississippi valley Upper Coal Measures. These beds derive an additional interest from the fact that on Poteau mountain 1000 feet of shale, in which no fossils were sought for, lie above the thin layer from which the entire collection was taken; thus the chance of finding true Permian beds in that region are very good." From this it will be seen at once that the Arkansas section is regarded as representing the Des Moines and Missourian series of Missouri and Kansas, as embraced between the Mississippian limestones

[1] Bull. Geol. Soc. America, Vol. II, pp. 225-242, 1891.

[2] Trans. New York Acad. Sci., Vol. XV, pp. 50-61, 1895.

[3] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

[4] Loc. cit.

and the Cottonwood limestone of the central part of the last mentioned state.

A careful comparison of the species of fossils that are considered by Smith from the "Upper Coal Measures" with those from the Upper and Lower Coal Measures of other parts of the Western Interior basin brings out the fact that the Arkansas fauna not only does not necessarily indicate a "very high" position in the Upper Coal Measures of the zone containing it, but that it may be, and probably is, very low. Judging from the fauna alone, and as a whole, according to the palæontological standard of its nearest and most closely related districts — the Missouri-Kansas province, with which it is properly compared — the indications are that the age of the strata yielding it is not that of the "Upper Coal Measures" at all, but of the "lower division" — that is, of the Des Moines series of the more northern localities.

All of the Arkansas species, with very few exceptions, are, in Iowa, Missouri and Kansas, the most widely distributed forms. Most of them range from the base to the top of the Des Moines series, and continue on upwards. In the lower series the marine beds are almost wholly absent, only a few thin limestones being present in the whole succession. Nevertheless the same species that are found in Arkansas occur abundantly not only in the thin limestone layers, which are rarely more than a few inches in thickness, but also in the calcareous shales, and, in less numbers even in the bituminous shales.

Of the corals listed from Arkansas only one form has a range that is unusually "high" in the northern succession; all of the others start almost from the very base of the series. The crinoids and bryozoans are all common in the Lower Coal Measures. All fourteen species of brachiopods are of very frequent occurence in the lower coal division, many commencing down in the Mississippian. One possible exception is *Terebratula bovidens*, which at present appears to be absent from some of the lower Des Moines beds. Of the lamellibranchs, all twenty-two species are the most characteristic forms of the very base of the Missourian; one-half of the number are found lower down, and no less than seven are typical Des Moines forms, in fact having an *optimum habitat* not in the marine beds but in the bituminous shales. The seven species of glossophora that are enumerated are the most abundant forms of the Lower Coal Measures throughout the northern district, and they are preeminently the characteristic fossils of the black shales everywhere. Among the ten cephalopods named, no less than five are of common occurrence in the Des Moines beds, and not infrequently they are found in the black shales; the other five, so far as known, range low in the Missourian.

If the faunal evidence, as recently presented, is to be relied upon at all, it would appear that there are no grounds for believing that there are necessarily present in the deposits of the Arkansas valley region any strata higher than the base of the Missourian series of Missouri and Kansas.

There is, however, another reason for believing that no part of the Missourian series, or its equivalent, exists in Arkansas. The general stratigraphy as far as it is now understood, gives not only no indication of the Missourian beds being represented in the region, but points almost conclusively to their absence.

The broad belt of lowland, lying below the contour of 1000 feet, and between the Ozark uplift and the elevated region of the Great Plains, extends from the Missouri river southwestwardly into Indian Territory and then eastwardly through the Arkansas valley to the savannas of the Mississippi embayment. This lowland is occupied chiefly by shales which have relatively much less resistant powers to erosion than the limestones on either side of the belt. In Missouri the subdivisions of the Coal Measures, both "Upper" and "Lower," have been clearly made out. In Kansas Haworth[1] has traced the same divisions to the Indian Territory line, so that down to the juncture of the great lowland valley and that of the Arkansas, the surface distribution of the several formations of

[1] Univ. Geol. Surv. Kansas, Vol. I, 1896.

the Carboniferous is well known. In Indian Territory the information is not yet as full as would be desirable. Still there are enough facts at hand to indicate the general features of the main subdivisions, or series. The Missourian, or more strictly marine series, composed of important limestones, does not appear to extend down the Arkansas valley into Arkansas, nor to change very much in lithological character. The Pawhuski limestone in eastern Oklahoma, regarded by Smith[1] as representing the same horizon of "Upper Coal Measures" farther east, certainly cannot be stratigraphically equivalent to any part of the Coal Measures that exist in the same latitude in Indian Territory. While it is not yet known with certainty just what its exact equivalent is, it is quite probable that it is the southern extension of what is termed the Iola limestone in the region to the north. If this is the case, the position of the limestone exposed in the quarries at Pawhuski is very near the base of the Missourian, or "Upper Coal Measures."

If, as now appears probable, the enormously thick Coal Measures of the Arkansas valley are practically the exact equivalents of only the lower division, or the Des Moines series of the region farther north, instead of representing the entire interval between the Mississippian and the so-called Permian (Oklahoman), or that part of the Carboniferous above the Cottonwood limestone in Kansas and Oklahoma, the explanation of the great increase in the thickness southward, would seem still more difficult. There have been, however, a number of new facts recently brought out regarding the diastatic changes that have taken place in the Ozark region, and some of these have a direct bearing upon the question under consideration.

It has been lately shown[2] that during the Kaskaskia, or closing epoch of early Carboniferous times in the Mississippi valley, there was a series of rapid changes in the relations of land and sea. At the beginning of the Kaskaskia the shore line had moved southward 400 to 500 miles at least from the

[1] Proc. Amer. Philos. Soc., Vol. XXXV, p. 230, 1896.

[2] Bull. Geol. Soc. America, Vol. III, p. 296, 1892.

latitude it occupied during the St. Louis, or approximately to the latitude of the present mouth of the Missouri River. This permitted erosion of the land surface north of this point; and immediately south of it the disposition of coarse sediments, covering the other marine beds of the Mississippian. Marine deposits of the later Kaskaskia, were again laid down over the coastal deposits of the same region. With a further recession of the sea some of the territory occupied by Kaskaskia rocks was also made land and was subjected to erosion. According to the recent suggestions of Marbut[1] the shore line at this time, when it had traveled farthest to the southward, coincided very nearly with the present crest of the Ozark uplift, that extends along a line drawn from Iron Mountain to the southwest corner of the state of Missouri.

It is now a well-established fact that everywhere to the north of the present Ozark crest profound erosion took place between the time when the St. Louis limestone was deposited and that when the Coal Measures were formed. Moreover, the effect of this land degradation must have left the country very much in the condition of a peneplane, for the old land surface is a rather even one, with no marked contrasts of relief. It beveled the previously slightly tilted strata, for the Coal Measures rest on the rocks of all ages from the Silurian to the top of the Lower Carboniferous. This stratigraphic hiatus, represented by the plane of unconformity at the base of the northern Coal Measures, manifestly indicates an episode in the physical history of the region, the importance of which has been heretofore little appreciated.

In the southerly retreat of the sea during the close of Lower Carboniferous time, there was, of course, a point beyond which the shore line did not advance. Beyond this point, seawardly, deposition went on uninterruptedly, the succession of beds was continuous, and the layers were conformable throughout the Carboniferous system. Such conditions appear to have prevailed in the region of southern Missouri and northern

[1] Missouri Geol. Surv., Vol. X, p. 82, 1896.

Arkansas. South of the Ozark crest, if the inferences already drawn are to be relied upon, deposition was continuous, not only through the Lower Carboniferous period, but also during the

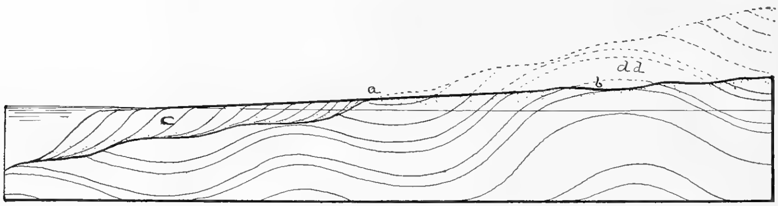

FIG. 1.—Ideal Conditions of Sedimentation.

interval when the region farther north was a land surface being rapidly eroded. As shown elsewhere,[1] the present Ozark dome had, of course, not begun to bow up. It was not a large island during the Carboniferous, as has been generally regarded. The

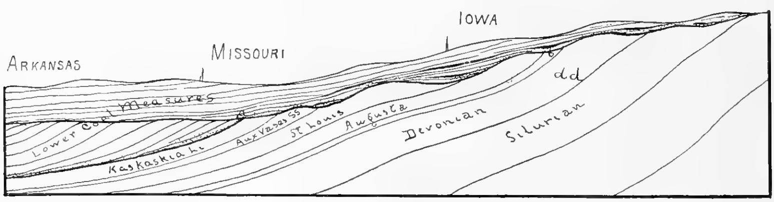

FIG. 2.—Cross Section of Mississippi Basin—Minnesota to Arkansas.

products of land degradation were, without doubt, dumped into the adjoining seas, just as the sediments of the present continent are being carried into the ocean to form the thick fringe of coarse shore deposits.

In general, the deposition of coarse sediments along the coast must have been represented by degradation on land. This phenomenon may be shown by the subjoined sketch (Fig. 1), in which *a* is the original shore line; *b*, the land surface; *c*, the sediments removed and transported from the eroded parts of the strata *d*, *d*, which had been subjected to deformation since their formation. Identically the same conditions obtained in the case

[1] Missouri Geol. Surv., Vol. VIII, p. 352, 1895.

of the Carboniferous deposits of the Continental Interior. It is also representative of the conditions existing at the present day on the Gulf coast, and is typical of sedimentation generally.

A diagrammatic cross-section, north and south, from Minnesota to central Arkansas, and representing the relations of the Carboniferous deposits of the region, is given in Fig. 2.

The true marine beds of the Missourian series, or "Upper Coal Measures," may have extended, and probably did stretch out over a considerable part, and possibly all, of the region; but erosion, since Carboniferous times, has removed all traces of these deposits.

CHARLES R. KEYES.

ON THE ORIGIN OF CERTAIN SILICEOUS ROCKS.

I. NOTES ON ARKANSAS NOVACULITE.

An examination of the residues of specimens representing both the Ouachita and Arkansas (commercial) types of novaculite confirms Griswold's observations and conclusions made on thin sections. Ground in an agate or porcelain mortar, the greater part of the rock is easily reduced to a fine slime that readily floats away in water. A considerable portion, however, consists of granules which, though made up of fine grains, require considerable rubbing to reduce them to slime. Even when, in the final stages of the grinding, a soft pestle is employed to avoid breaking up the grains of quartz and other minerals, a considerable number of the aggregated granules remain, thus showing a strong cohesion of the constituent grains.

The amount of quartz in simple grains that can be positively identified by the polarization colors is not large, and for the most part is not distinctly detrital. Such grains are frequently enclosed in the composite ones or have composite silica adhering to them, and often appear to be more completely developed individuals of the aggregated grains. In many cases, however, they appear to be detrital grains with adherent secondary silica. Unmistakable detrital grains are represented by numerous zircons and rare fragments of tourmaline and garnet.[1] These are exceedingly fine, and both in character and amount seem to confirm Griswold's conclusion that the deposit took place in still and comparatively deep water into which only a small amount of very fine detritus would be floated.

The great bulk of the silica of these rocks appears to be secondary, and to account for its peculiarities the replacement hypothesis of Rutley seems to offer less difficulty than that of

[1] Wichmann found garnets in the novaculites of the Marquette, Mich., district in 1879. Q. J. Geol Soc., Vol. XXXV, 1879, pp. 156–164, J. C. Branner.

an originally siliceous sediment of Griswold. The latter must either have been chemical, which Griswold expressly rejects, and apparently very properly, or composed of very fine granular quartz. In the latter case the granules, however fine, have been still further granulated, a species of metamorphism which has apparently not been observed elsewhere, and which is difficult to conceive. The metamorphism, if there had been any, would rather be expected to be in the direction of larger and well-defined grains of quartz, such as were noted in some of Griswold's slides (No. 14).[1] The latter slide seems to be a case of replacement according to Rutley's hypothesis "caught in the act." It may be suspected that in a larger suite, especially of non-commercial stones, other such cases might be found.

Griswold's explanation of the cavities seems also to point in the direction of a replacement, and can be reconciled with Rutley's hypothesis on the supposition, which does not seem difficult, that part of the original calcareous sediment may have crystallized (not necessarily as dolomite) and thus have offered greater resistance to the replacement.

The description of the beds also is suggestive of original limestones with cherty layers and nodules. Two of the specimens sent appear to me to represent such cherts, though I should not call them metamorphosed.

The question of the state of the silica seems to me to be one of quite secondary importance, as in the case of silicified wood replacement silica is met with in all states, and often with an appearance of a passage to the state of quartz after the replacement.

Viewing the question from a distance, and on a very insufficient basis, it seems probable that if Mr. Griswold had taken into consideration the hypothesis of a replacement of calcareous sediments, he would, perhaps, have found much more in its favor than either Rutley or I could see.

For the study of crucial points, "non-commercial" rock will

[1] Whetstones and the Novaculites of Arkansas. By L. S. GRISWOLD. Ann. Rep. Geol. Surv. Ark. for 1890, III, p. 128.

probably be often better than the "commercial," and the preparation and examination of residues more rapid and satisfactory than that of microscopic sections.

ORVILLE A. DERBY.

SÃO PAULO, Brazil, April 6, 1898.

II. ON THE ORIGIN OF NOVACULITES AND RELATED ROCKS.

The preceding part of this paper was recently received by me from Professor O. A. Derby as embodying the results of his examination of novaculites by a method hitherto not employed with those rocks. It should be added that in a former letter he sent me the results of a study by this same method of an impure cherty Carboniferous limestone from Tieté, São Paulo. In this limestone he found by crushing and washing, rolled quartz, zircon, rutile, garnet, tourmaline, etc.

These notes I have taken the liberty to publish without consulting Professor Derby in order that the results of his work may become available for others who may study this interesting and important group of rocks.

It is remarkable that so many different views have been held regarding the origin of novaculites and of the closely related highly siliceous rocks known as jaspilites and sometimes as jaspers, siliceous shales, etc.

The following theories have been advanced to explain the origin of these rocks:

Foster and Whitney seem to have regarded the jaspers of Michigan[1] as segregations of eruptive origin. Owen considered the Arkansas novaculites as metamorphosed sandstone.[2]

Kimball believed the Marquette iron ores and their associated jaspers to be metamorphic rocks of sedimentary origin, presumably mechanical.[3]

[1] Geology and Topography of the Lake Superior Land District. Pt. II. The Iron Region, pp. 67–69, 1851.

[2] Second Geol. Surv. Ark., pp. 23, 25, 1860.

[3] Am. Jour. Sci., Vol. XXXIX, p. 303, 1865.

Crosby thinks some of the jaspers and quartzites are the siliceous oozes of the deep sea, that is, that they are of organic origin.[1]

Wadsworth at first believed in an eruptive origin for the jaspilites.[2] This view he modified later.

Julien believes in the mechanical sedimentary origin of the jasper iron ores of the Marquette region, and it is to be presumed that he considers the jaspers mechanical sediments also.[3]

Irving concluded that the jaspers were formed by silica replacing dolomite or calcite.[4]

Reyer thinks the sediments associated with the iron ores of Michigan are derived partly from decomposed igneous rocks and partly from organic remains.[5]

Branner has suggested that the compact novaculites may be metamorphosed cherts.[6]

Comstock considered many of the Arkansas novaculites to be hot water deposits.[7]

Julien thinks amorphous silica is produced by marine organisms, or by precipitation from solutions.[8]

Griswold is of the opinion that novaculites are simply metamorphosed, fine grained, mechanical sediments.[9]

N. H. and H. V. Winchell believe in the theory of chemical precipitation for the jaspilites.[10]

James E. Mills is of the opinion that certain quartzites of the

[1] Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 167–168, 1878–1880.

[2] Bull. Mus. Comp. Zool., Vol. VII, p. 30, 1880; Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 477–478, 1878–1880; Bull. Mus. Comp. Zool. Harvard Col., Geol. Ser. I, Vol. XVI, pp. 331–565, 1884.

[3] Genesis of the Crystalline Iron Ores. By A. A. Julien. Eng. Mining Jour., Vol. XXVII, pp. 81–83, 1884.

[4] Am. Jour. Sci., Vol. XXXII, p. 255, 1886.

[5] Geologie der amerikanischen Eisenlagerstätten. E. Reyer. Oest. Zeitsch. f. Berg. u. Huttenwesen, XXXV, Nos. 10 and 11, 1887.

[6] Ann. Rep. Geol. Surv. Ark., Vol. I, p. 49, footnote, 1888.

[7] Ann. Rep. Geol. Surv. Ark., Vol. I, pp. 95, 129, 1888.

[8] Proc. A. A. A. S., Vol. XXVII, pp. 311–340, 1889.

[9] Ann. Rep. Geol. Surv. Ark., Vol. III, pp. 164, 194, 1890.

[10] The Iron Ores of Minnesota. By N. H. and H. V. Winchell. Minneapolis, 1891, p. 74.

Sierras, in California, are replacements of clays by silica,[1] and that others are possibly replacements of limestone by silica.

Wadsworth came to believe in their sedimentary origin.[2]

Rutley in a review of the subject reached the conclusion that the novaculites were replacements by silica of dolomites or of dolomitic limestones.[3]

Hinde expressed the opinion on the occasion of the reading of Rutley's paper that these rocks were of organic origin.[4]

Lawson thinks the "radiolarian cherts," that is, the jaspers of the coast ranges of California, are local deposits chemically precipitated from submarine siliceous springs.[5]

Branner thinks the jaspers are of organic origin.[6]

Van Hise in speaking of certain jaspers of the Marquette district says: "It appears highly probable that dynamic action transformed the ferruginous chert into the jasper."[7]

Derby's views, that novaculites are replacements of limestones by silica, are given in the first part of the present paper.

Fairbanks has concluded that the Tertiary siliceous shales of the coast ranges of California are derived from diatomaceous beds.[8]

Doubtless many other expressions of views regarding the origin of these siliceous rocks might readily be found, but these are enough to show that there has been the widest possible difference of opinions on the subject.

We have then the following theories, that the novaculites, jaspilites, jaspers, etc., are:

1. Mechanical silts.
2. Organic silts.

[1] Bull. Geol. Soc. Am., Vol. III, pp. 421–422, 440, 1892.

[2] M. E. WADSWORTH, Rep. State Geol. for 1891–2. State Board of Geol. Surv. (of Michigan) for 1891–2. Lansing, 1893, pp. 75–155, dated March 1892.

[3] Quart. Jour. Geol. Soc., Vol. L, p. 386, 1894.

[4] Quart. Jour. Geol. Soc., Vol. L, p. 391–392, 1894.

[5] 15th Ann. Rep. U. S. G. S., pp. 425–426, 1895.

[6] Trans. Amer. Soc. C. E., Vol. XXXIX, p. 58. Read Nov. 17, 1897.

[7] Monog. U. S. G. S., Vol. XXVIII, p. 372, 1897.

[8] San Luis Obispo folio, U. S. G. S. (MSS.).

3. Chemical precipitates.
4. Igneous deposits.
5. Replacements of clays.
6. Replacements of limestones.
7. Replacements of dolomites.

The most comprehensive discussions of this subject are those of Griswold and of Rutley. But these writers do not agree in regard to the origin of the rocks, the former believing them to be fine sediments, the latter believing them to be replacements of dolomites or limestones.

My own opinions have not been based upon such microscopic study as either Griswold or Rutley devoted to this work, and for that reason were not worthy of special consideration. Since I began to study the geology of the coast ranges of California, however, I have, I believe, seen much that throws light upon the origin of the novaculites and similar rocks.

These observations embrace those upon geological structure, gross and microscopic structure, composition and geological relations, and lead me to believe that the white siliceous shales so characteristic of the Tertiary, the jaspers and the diatomaceous beds are only various phases of the same thing.

I am glad to say that Dr. H. W. Fairbanks, whose acquaintance with the coast range geology makes his opinion especially valuable, expresses similar views on this subject. Dr. Fairbanks, however, has undertaken a thorough study of this subject from which important results may be expected.

J. C. BRANNER.

STANFORD UNIVERSITY, CALIFORNIA.
June 4, 1898.

A STUDY OF SOME EXAMPLES OF ROCK VARIATION.[1]

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In the following article I purpose to describe briefly a series of igneous rocks which vary from those of acid character through those of intermediate and basic characters to others which are ultrabasic in composition. The rocks occur upon the upper peninsula of Michigan, in the vicinity of Crystal Falls, the most important town in the iron-bearing district of the same name. All are to be found in an area extending from Crystal Falls southeast to a mile east of the Michigamme River. In the description of the various kinds no detailed mention of localities will be given, since they are given in the complete article, and if wanted can readily be found by reference to it. The rocks occur as knobs or groups of knobs, and as well determinable dikes cutting the knobs. The outcrops project through an area covered by glacial deposits. The best exposures are naturally near the river, where erosion has removed the drift mantle.

Here and there in the drift are isolated exposures of sedimentary rocks of Upper Huronian age. The relations of the igneous rocks to the sedimentaries are not shown by exposures of direct contacts, but it is inferred from the occurrence of sedimentaries between the igneous exposures that the drift is underlain by Upper Huronian sedimentaries, and that the igneous rocks are intrusive in them. The intrusives have never been found to penetrate the superimposed, horizontal, Lake Superior, Potsdam sandstone. These facts are conclusive proof that their period of

[1] This article is a brief abstract of a part of a report which will appear in full as a monograph of the U. S. Geol. Surv., under the title of "The Crystal Falls Iron-bearing District of Michigan." For details which are not warranted in this place the reader is referred to the monograph. An abstract of the monograph, in which the portion treated in the present article is barely mentioned on account of lack of space, will be published under the same title as the monograph in the 19th Annual Report.

intrusion fell in the time between the deposits of the Upper Huronian and those of the Cambrian. In the complete article there is a discussion of the time of the folding of the Upper Huronian, and the conclusion is reached that this folding took place immediately preceding the deposit of the Keweenawan series. If these intrusives had existed at that time, they must certainly have suffered from the orogenic movements. Examination of the exposures of the intrusives has not shown schistose masses, nor has detailed microscopical study disclosed any textures which accompany powerful dynamic movements, except in isolated cases which are presumed to be due to purely local movements. Such being the case, the conclusion follows that these intrusives are subsequent in their origin to the folding of the Upper Huronian; that is, are of Keweenawan or of post-Keweenawan age.

It seems highly probable, though it cannot now be proven, that the intrusives are contemporaneous with the period of volcanic activity, during which the heterogenous Keweenawan series was formed. During the formation of such a great series we might well expect more or less fissuring of the sedimentaries and intrusion of molten magma in a district no farther removed from the scene of eruptive activity than is the Crystal Falls district from the Keweenawan, a distance of about thirty miles. It is at least clear that the rocks are post-Huronian and pre-Potsdam, but a closer approximation cannot be made with certainty.

With few exceptions the intrusive rocks are medium to coarse-grained. While the granitic texture is unquestionably predominant, other textures are not absent, for we find some ophitic and porphyritic textured rocks, and others in which even a parallel (flow) texture has been produced. It has already been intimated that the chemical range is very great. There is, of course, a corresponding range in color.

The main classes with which the variations will be grouped are the diorites, the gabbros, or gabbro-norites, and the peridotites. Complete and accurate chemical analyses of certain rocks of these chief classes have been obtained and the microscopical diagnosis thereby confirmed. Within each of these main divisions well marked varieties can be distinguished. While between the gabbros and the peridotites a transition is unquestionable, a less positive statement must be made for the connection between the diorites and the gabbros, and while the writer is convinced that such connection exists, he is aware that the reader may not take the same position. In the following pages the three main classes will be briefly described, and then the variations within each class. The relations between the various main divisions will be described, and then, with a brief summary of the facts, the reader will be enabled to draw his own conclusions.

Diorites.—Following Brögger's definition,[1] the name diorite is in the following pages restricted to granitic textured plutonic rocks of intermediate acidity, consisting essentially of plagioclase and either primary hornblende, pyroxene, or mica, or two or more of these.

This is very different from the usage by a number of the previous writers on the Lake Superior region, who called the uralitized dolerites "diorites" or "epidiorites." As a result of the introduction of the use of this name diorite by scientific men, it is now in common use among the miners in the Lake Superior iron regions, and is usually applied by them to any greenish rock whose sedimentary characters are not clearly recognized, very much in the same way that the field geologist uses greenstone, especially if the green rock is associated with an iron formation. In the great majority of cases such rocks are dolerites in a more or less advanced stage of alteration, and rarely, if at all, pure diorites.

The dioritic rocks are of medium to coarse grain. In texture they show some variations from rocks of a granitic texture

[1] Die Eruptivgesteine des Kristianiagebietes, by W. C. Brögger in Videnskabsselskabets Skrifter, I Mathematisk- naturv. Klasse. Pt. I, Die Gesteine der Grorudit-Tinguait-Serie, 1894, No. 4, p. 93. Pt. II, Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, No. 7, p. 35.

to others which incline to the ophitic texture, and to still others which are distinctly micropegmatitic. The granitic texture is the most frequent. The color is uniformly light gray or reddish, but at times, when the ferromagnesian minerals are present in greater quantity, they become dark gray or greenish brown.

The important mineral constituents are feldspar, quartz, hornblende, and biotite. Apatite, zircon, sphene, iron oxide, and epidote (?) are the accessory minerals. The secondary minerals present are white and brown mica, chlorite, epidote, zoisite, calcite, and rutile. Plagioclase feldspar, orthoclase, and microcline occur together. The plagioclase is present in individuals which are fairly automorphic. In the ophitic textured diorites, the plagioclase is the best developed of any of the essential constituents. In the granitic textured rocks the degree of automorphism is highest where orthoclase and quartz are present in the largest quantity, and diminish as these diminish in consequence of the interference of the plagioclase individuals. For the most part the plagioclases yield rather narrow sections, though they can hardly be called lath-shaped. Measurements show the plagioclase to be andesine. It is very much altered. Orthoclase is present in large plates, which form a part of the mesostasis for the plagioclase and the bisilicates. The quantity of orthoclase varies considerably. It is very much decomposed. Microcline is not abundant. It is very fresh, and in many cases automorphic with respect to the orthoclase and quartz. Quartz is present in variable quantity, and with the orthoclase forms the mesostasis. The hornblende shows a good development in the prismatic zone. The terminal planes are not so well developed. It varies from dirty green to reddish-brown in color. The reddish-brown variety occurs in the center of the crystals and is surrounded by the green. The differently colored zones thus produced are not sharply delimited, and are also in perfect optical continuity. No evidence is found indicating the green kind to be an alteration product from the brown variety, and they are both assumed to be primary. The biotite is brown, and shows its usual characters. It is less well developed than the hornblende. All of the other minerals show their usual well-known characters.

According to the variations in the proportions of the essential minerals, plagioclase, orthoclase, quartz, hornblende, and biotite, we get the following varieties of diorite: quartz-diorite, tonalite, quartz-mica-diorite, and mica-diorite. This variation is best shown in a connected group of knobs composed of medium grained rock, which varies in color from light pink to a very dark greenish-gray. Areas of light and dark colored rock may be seen extending in finger-like projections into one another. There are no sharp boundaries between them, however, but, on the contrary, a gradual passage from the light to the dark variety. Some of the rocks also contain small, more or less rounded areas, which are clearly segregations of ferromagnesian minerals. These different phases evidently belong to a single rock mass, but the microscope enables a separation to be made into the several mineralogical and textural facies already mentioned. The main mass of the rock forming the knobs appears to be a tonalite which resembles the published description by Becke[1] of that from the Rieserferner. It also closely resembles some slides of the typical Adamello tonalite with which I have been able to compare it. This tonalite grades by diminution of biotite with corresponding increase of hornblende into quartz-diorite, and by a diminution or disappearance of the hornblende and increase of the biotite into a quartz-mica-diorite. Where the quartz of this last variety is practically wanting, we get a mica-diorite. In this small massif pure types of the rocks described are of rare occurrence. Orthoclase is present in all of these dioritic rocks. In certain facies the orthoclase and quartz are very abundant, and the plagioclase correspondingly subordinate. Such rocks approach closely the plagioclase-bearing granites.

The relationship to granites is better shown in a different

[1] Petrographische Studien am Tonalit der Rieserferner, by F. BECKE, Tsch. Mitt. Vol. XIII, 1892, pp. 379–464.

occurrence from the one just described, in which the greater portion of the rock is a plagioclase-bearing biotite-granite, showing in many cases most beautiful micropegmatitic texture, but with schlieren of a darker colored rock which might readily be called a quartz-mica-diorite. It is especially interesting to note also that this series of exposures is cut by a number of small dikes of uniform character, varying from fractions of an inch to three inches in width. The dike rock is very light gray to pink in color, and cryptocrystalline. Examined under the microscope, these dikes can be readily separated into a microporphyritic center, and a micrgranitic textured selvage. Phenocrysts of quartz, feldspar, and biotite lie in a micrgranitic groundmass of feldspar and quartz, between which occur secondary flakes of muscovite. The rock is a microporphyritic quartz-mica-diorite or quartz-mica-diorite-porphyry. This rock seems to bear a very strong resemblance to the tonalite-porphyrite described by Becke[1] which occurs as a dike facies of the Rieserferner tonalite to which I have already referred.

Still another illustration of the passage from the granitic to the dioritic rocks was observed upon a dike, four feet wide, which penetrates a knob of hornblende-gabbro. A specimen taken near the center of the dike discloses itself as a biotite-granite with a small amount of plagioclase. The sides of the dike consist of diorite, composed of andesine feldspar, and biotite, without any quartz. The sharp line of demarkation which exists between the dike and the gabbro seems to preclude the possibility of a fusion and mingling of the two rocks, such as has been suggested by Johnston-Lavis,[2] as in some cases causing variation in chemical composition of intrusive rocks, especially where this variation is one between the center and periphery of an intrusive mass. The diorite occurrences of the Crystal Falls district seem, in the gradations mentioned, to

[1] Loc. cit., pp. 434–441.

[2] The causes of variation in the composition of igneous rocks, by H. J. JOHNSTON-LAVIS: Natural Science, No. 4, pp. 134–146.

The basic eruptive rocks of Gran, Norway, and their interpretation, by H. J. JOHNSTON-LAVIS: Geol. Mag., 4th decade, Vol. I, 1894, p. 252.

be very similar to the tonalite from the Rieserferner described by Becke,[1] and also to the so-called grano-diorite massifs of California, described by Becker, Turner,[2] and Lindgren.[3] The grano-diorite of California appears from Lindgren's description to correspond very closely to tonalite, though Turner uses the name as synonymous with quartz-mica-diorite.

It has not been found possible thus far to obtain analyses of all these varieties. The more acid facies of the diorites seem to show very clearly their gradation towards tonalites and granites, and, from their content of free silica, the conclusion seems to be warranted that they are rather acid. Such being the case, it was deemed of more importance to study the relations of the less acid dioritic facies in order to determine their relationship with the basic gabbros and peridotites with which their connection is not so evident as it is with the granites. To this end a complete analysis was made by Dr. H. N. Stokes of a mica-diorite. The rock analyzed consists of biotite, hornblende, plagioclase, orthoclase, and quartz, with the biotite and plagioclase as the predominant characteristic constituents.

ANALYSIS OF MICA-DIORITE BY DR. N. H. STOKES.

SiO_2	58.51	MgO	3.73
TiO_2	.72	K_2O	4.08
Al_2O_3	16.32	Na_2O	3.11
Cr_2O_3	none	H_2O at 110°	.23
Fe_2O_3	2.11	H_2O above 110°	2.00
FeO	4.43	P_2O_5	.30
MnO	trace	CO_2	none
NiO	none		
CaO	3.92		99.46

Gabbros and norites.—The gabbros and norites are holocrystalline rocks of moderately fine to coarse grain. The rocks here included show a considerable variation in texture. Some

[1] Op. cit.

[2] Geology of the Sierra Nevada, by H. W. TURNER: 17th Ann. Rep. U. S. Geol. Surv., No. 1, 1896, pp. 636–724.

[3] Granitic rocks of California, by W. LINDGREN: Am. Jour. Sci., 4th series, Vol. III, 1897, p. 308. Here can be found reference to earlier articles on grano-diorites.

of the finest grained forms possess a very good parallel texture. Others are noticeably porphyritic. A few have a poikilitic texture. Less common is an approach to the ophitic texture of the dolerites. Most commonly of all, however, the rocks are granitic in texture. The color variation is not great, and is chiefly in dark brown or greenish-black tones. The important mineral constituents are feldspar, biotite, hornblende, pyroxene, and olivine. Apatite, sphene, zircon, rutile, octahedrite, brookite (?), and iron oxide occur as accessory minerals. White and brown mica, chlorite, hornblende, talc, serpentine, sphene, rutile, and calcite occur as secondary minerals.

Plagioclase and orthoclase-feldspar are both present. The last is, however, of doubtful occurrence. The plagioclase is labradorite, and shows its usual characters.

Hornblende is the most striking component in the majority of the sections. It is present in three different varieties, all of which occur in anhedra. The most prominent kind is a reddish-brown hornblende, which has a dark green hornblende commonly associated with it, and frequently in zonal intergrowth with it. This hornblende occurs without the green kind, but the green is invariably associated with the brown variety. The two are optically continuous in the intergrowth. It is possible, though not susceptible of proof, in the sections examined, that the green hornblende is the incipient alteration of the brown hornblende. The pleochroism is strong in the following colors:

Brown hornblende.

a	b	c
Light yellow or red, with tinge of green.	Reddish-brown.	Same as b, or else a darker reddish-brown. Exceptionally it is a light yellowish-brown.
		c > b >> a

Green hornblende.

a	b	c
Greenish-yellow.	Yellowish or brownish-green.	Darker olive-green. Frequently with bluish tinge.
		c > b > a

This hornblende, with respect to its rather exceptional pleochroism and its general characters, seems to agree very well with that described by van Horn[1] from very similar rocks from Italy, and like that is possibly very basic. The brown hornblende possesses a further interest in that it is frequently rendered very dark by the number of exceedingly small inclusions within it, and in this, and also in its color, resembles so strongly hypersthene as to be readily mistaken for it upon cursory examination. The inclusions referred to are determined to consist of characteristic heart-shaped and geniculate twins of rutile, and pointed pyramidal crystals of octahedrite. Others show a flat tabular development, somewhat similar to that of brookite, though these could not be positively determined as that mineral. Associated with the above were numbers of hexagonal, clove-brown plates appearing in cross section as sharp lines. A gradation between these plates and large masses of ilmenite was traced. It thus appears that these inclusions are all titaniferous minerals.

The second kind of hornblende is the compact, strongly pleochroic common green hornblende, and the third kind is a non-compact reedy variety of light green hornblende. This last is probably secondary, but secondary after the original hornblende, thus not affecting essentially the character of the rock.

The pyroxene is represented by a monoclinic variety and by the orthorhombic bronzite. The presence of olivine was determined with considerable doubt. None of the remaining minerals show anything of special interest.

The leading essential constituents described are combined in variable quantities, and accordingly a number of different mineralogical types of rocks are produced. The important types which will be described are hornblende-gabbro, consisting essentially of hornblende and labradorite; gabbro, consisting of monoclinic pyroxene and labradorite; and bronzite-norite, com-

[1] Petrographische Untersuchungen über die Noritischen Gesteine der Umgegend von Ivrea in Oberitalien, by F. R. van Horn. Tsch. Mitt., V Heft, 17 Bd., 1897, p. 409.

posed of bronzite and labradorite. These various mineralogical types exhibit very interesting ranges in texture, to which attention will be called. The hornblende-gabbro of granitic texture is the prevailing rock. An analysis of such a rock shows the following composition:

ANALYSIS OF HORNBLENDE-GABBRO BY MR. GEORGE STEIGER.

SiO_2	49.80	Na_2O	2.22
TiO_2	.79	H_2O 100°−	.13
Al_2O_3	19.96	H_2O 100°+	1.71
Fe_2O_3	6.32	P_2O_5	.07
FeO	.49	CO_2	.15
CaO	11.33		
MgO	7.05		100.63
K_2O	.61		

In one of the hornblende gabbros a porphyritic texture is very pronounced. Porphyritic brown hornblendes, which are poikilitic from inclusions of feldspar and a few grains of augite, lie in an imperfectly ophitic groundmass. This rock grades into a finer grained nonporphyritic granitic textured gabbro. Both mineralogical and textural variations are well shown in another occurrence, in which the relations of the respective varieties are clearly seen. The normal granitic hornblende-gabbro is cut by numerous narrow bifurcating dikes, which are very dark, of fine grain, and stand out clearly from the main mass of the coarse-grained gabbro. These dikes contain a larger percentage of biotite than is found in the normal gabbro, but most interesting is the presence along the sides of the dikes of a well-marked parallel arrangement of the minerals. This is presumed to be a true flow structure consequent upon the flowage of the magma, where it was forced in the fissures, as none of the minerals bear indications of secondary origin, and show but faint evidence of the effects of pressure.

These dikes, as well as the main mass, are cut by a coarse-grained bronzite-norite. Bronzite, hornblende, and labradorite are the essential constituents of this rock, arranged in order of their importance. The following analysis gives its chemical composition:

ANALYSIS OF BRONZITE-NORITE BY MR. GEORGE STEIGER.

SiO_2	48.17	Na_2O	1.34
TiO_2	1.00	H_2O { 100° −	.19
Al_2O_3	25.26	H_2O { 100° +	2.00
Fe_2O_3	1.13	P_2O_5	.07
FeO	6.10	CO_2	.43
CaO	9.53		
MgO	4.22		100.17
K_2O	.73	MnO, etc., not looked for.	

The last gabbro occurrence to be mentioned is one in which we find the normal type of hornblende-gabbro cut by a dike in which monoclinic pyroxene is in about equal quantity with the hornblende. This evidently represents a transition towards a true gabbro. This exposure of gabbro is cut by a peridotite, which is feldspathic and concerning which detailed statement will be made in the following pages.

The rocks just described may be compared in their variation to those described by G. H. Williams [1] from Maryland, by Chester [2] from Delaware, and by Fairbanks [3] from California. A series of basic rocks similar in many respects to those of Crystal Falls has also been described recently in two interesting papers by van Horn [4] and Schaefer.[5]

Peridotites.—The peridotites are all coarse-grained rocks of very dark color, consisting of the following chief mineral con-

[1] The gabbros and associated hornblende rocks occurring near Baltimore, by G. H. WILLIAMS, Bull. U. S. Geol. Surv., No. 28, 1886. Outline of the geology of Maryland, Baltimore, 1893, p. 39.

[2] The gabbros and associated rocks in Delaware, by F. D. CHESTER, Bull. U. S. Geol. Surv., No. 59, 1890.

[3] The geology of Point Sal, by H. W. FAIRBANKS, Bull. Dept. of Geol., Univ. of Cal., Vol. II, No. 1, 1896, p. 56 et seq.

[4] Petrographische Untersuchungen über die noritischen Gesteine der Umgegend von Ivrea in Oberitalien, by F. R. VAN HORN, Tsch. Mitt , Vol. 17, 1897, pp. 391–420.

[5] Der basische Gesteinszug von Ivrea im Gebiet des Mastallone–Thales, by R. W. SCHAEFER, Tsch. Mitt., Vol. 17, 1898, pp. 495–517.

CORRECTED ANALYSIS.

THERE is given upon this sheet the corrected analysis of the bronzite-norite described upon page 382 of the May-June number of this JOURNAL. The tables containing percentages of chief oxides, etc., have been calculated from this analysis, corresponding to those formerly given upon pages 387–8, and are also given here. It is requested that these analyses and tables be substituted in the places indicated by the table and page numbers which accompany them.

ANALYSIS OF BRONZITE-NORITE BY MR. GEORGE STEIGER.

Page 382.

SiO_2	48.23	Na_2O	1.34
TiO_2	1.00	H_2O 100 −	.26
Al_2O_3	18.26	H_2O 100 +	2.00
Fe_2O_3	1.26	P_2O_5	.07
FeO	6.10	CO_2	.43
CaO	9.39		
MgO	10.84		99.91
K_2O	.73	MnO, etc., not looked for.	

Table I, page 387

	3
SiO_2	48.23
TiO_2	1.00
Al_2O_3	18.26
Cr_2O_3	
Fe_2O_3	1.26
FeO	6.10
MnO	——
NiO	——
CaO	9.39
MgO	10.84
K_2O	.73
Na_2O	1.34
H_2O 100−	.26
H_2O 100+	2.00
P_2O_5	.07
CO_2	.43
	99.91

Table II, page 387

	3
SiO_2	49.64
TiO_2	1.03
Al_2O_3	18.79
Fe_2O_3	1.30
FeO	6.28
CaO	9.67
MgO	11.16
K_2O	.75
Na_2O	1.38

Table III, page 388

	3
Si	45.27
Ti	.71
Al	20.26
Fe	5.70
Ca	9.51
Mg	15.22
K	.88
Na	2.45

stituents: pyroxene (monoclinic and orthorhombic), olivine, hornblende, and biotite. Associated with them are feldspar, apatite, green and brown spinel, and iron oxide. The relative proportions of these minerals differs much, and yield different well-known rocks. The types are not sharply separated, but are found, both in the field and under the microscope, to grade into one another. The purest form of peridotite is the wehrlite, composed essentially of olivine and augite. Where, besides these minerals, hornblende is present in large quantities, the rocks belong to the amphibole peridotite type and approach Williams' cortlandtite. In some specimens the biotite is almost in sufficient abundance to warrant the naming of the rock biotite-peridotite. Again, feldspar is present in comparative abundance and the rock is a feldspathic wehrlite, and approaches an olivine-gabbro or an olivine-hornblende-gabbro.

A number of exposures of the peridotites have been examined, but only one will be described here, and that has already been referred to under the gabbros. This peridotite cuts the gabbros. Sections made from different specimens taken from the exposure would be named, if considered separately, amphibole-peridotite, wehrlite, or even olivine-gabbro. This is the same exposure from which was taken a specimen described by Patton [1] as hornblende-picrite. In this rock there occur the following essential mineral constituents, given in order of crystallization: augite and olivine, apparently contemporaneous, orthorhombic pyroxene, hornblende, biotite and feldspar.

Of the mineral constituents forming the rock, augite is the only one which is automorphic, and then only when it is partially or wholly surrounded by feldspar. The olivine is in rounded individuals which are never associated with the augite in such a way as to enable their relative periods of crystallization to be determined. Orthorhombic pyroxene, apparently bronzite, occurs in grains inclosed in hornblende, and also forms

[1] Microscopical study of some Michigan rocks, by H. B. PATTON, in Sketch of the geology of the iron, gold, and copper districts of Michigan, by M. E. WADSWORTH, Rept. State Board Geol. Surv. for 1891, 1892, 1893, p. 186.

a narrow zone around the olivine. The hornblende is predominately a brown variety, showing strong pleochroism ; $\mathfrak{a}$ is light cream yellow, $\mathfrak{c}$ is yellowish-brown, and $\mathfrak{b}$ is reddish-brown. $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$. Patton [1] has already called attention to the exceptional pleochroism of this hornblende, in which the brownish color is that of rays vibrating parallel to the orthodiagonal axis. The brown hornblende is accompanied by a small quantity of green hornblende, which is in crystalline continuity with the brown, and is apparently original. The biotite began to crystallize before the hornblende had ceased growing, as we find it in ragged plates included by it, especially upon the periphery of the individuals. It is normally the least well-developed mineral present. Feldspar is present at times in small quantity, and forms the mesostasis. The olivine possesses a certain interest, as it is surrounded by zones[1] of different minerals; first, orthorhombic pyroxene, surrounded in its turn by green compact hornblende, which is in optical continuity with the predominant brown hornblende of the rock. This green hornblende lies next to the feldspar, and is traversed by anastomosing tabular feldspar growths.

From the relations described as existing between the various minerals composing the peridotite, it seems that the following stages may be outlined in the progress of the consolidation of this rock: From the coarse, even-grained character, and from the fact that neither a fine-grained groundmass nor glass is present, the conclusion is warranted that it consolidated very slowly, and must have, of course, at some time been under very high temperature. The olivine and augite were the first of the chief silicate constituents to form, and crystallized out of the magma at approximately the same time. The magma soon reached a condition unfavorable for further production of olivine, probably on account of increasing acidity. There was then formed the orthorhombic pyroxene occurring in a zone surrounding the olivine. The monoclinic pyroxene continued to grow during the formation of this orthorhombic variety, as it is

[1] Loc. cit., p. 186.

not surrounded by it. Finally, however, the condition of the magma was such that in the place of the monoclinic and orthorhombic pyroxene the crystallization of hornblende began.

I do not know what the conditions were which caused the formation of the hornblende subsequent to and in such intimate association with the pyroxene, surrounding it in zonal growth. An explanation of such occurrences has been attempted by Becke[1] in a recent article in which the conclusion is reached that the formation of hornblende and pyroxene depends upon changes in temperature and pressure. His explanation is based upon the facts of occurrence of pyroxene and hornblende in plutonic and effusive rocks, and also upon the well-known fact that at high temperature and atmospheric pressure hornblende cannot exist, but when fused recrystallizes as pyroxene, and upon the experiments of von Chrustschoff,[2] who has obtained hornblende at a temperature of 550° C., with the presence of water, under which conditions a high pressure must be developed. However, attention should be called to the fact that his explanation does not take into account other important factors which certainly influence the crystallization of minerals, for example, the chemical composition of the magma, and the fusion point and specific gravity of the minerals.

Whatever the factors are which determine its crystallization, the fact is that hornblende began to crystallize in the place of pyroxene. The biotite appears to have been formed at this time with the hornblende. The production of the hornblende and biotite continued until the remaining magma had reached the composition of basic feldspar, which then crystallized and now forms the mesostasis. A zone of orthorhombic pyroxene succeeded by one of hornblende has been described as surrounding the olivine in this peridotite. The term "reaction-rims" has been

[1] Gesteine der Columbretes ; Anhang : Einiges über die Beziehung von Pyroxen und Amphibol in den Gesteinen. By F. BECKE : Tsch. Mitt., Vol. 16, 1896, pp. 327–336.

[2] Bull. de l'Academie des Sciences, St. Petersburg, 1890, 13. Cf. BECKE, loc. cit., p. 337.

applied to similar zones by various observers. It seems to me that this term is inapplicable to such zones. It is not probable that in such a case as this there is a reaction in a strict sense between the magma and the olivine. Moreover, the zones should not be compared to the "resorption-rims" found so commonly in certain effusive rocks, where, from the fusion of hornblende crystals, pyroxene has been produced. Such a zonal growth around the olivine seems to me comparable to the case described by Washington,[1] where colorless diopside phenocrysts are surrounded by a narrow border of yellowish-green augite, which corresponds to the small augites in the groundmass, or to those cases which are so common in plutonic rocks, even in this rock described, where hornblende is found surrounding the pyroxene.

A general explanation which would account for the successive crystallization of pyroxene and hornblende in this rock should be applicable to such a zonal growth as occurs around the olivine, taking into consideration, of course, the probability that a factor of slight importance in the one case may be the controlling factor in the other. Such occurrences seem clearly to indicate a change in the chemical composition of the magma as the chief factor, but influenced more or less strongly by the pressure, the temperature, and also by other factors.

An analysis of this peridotite is given below:

ANALYSIS OF PERIDOTITE BY DR. H. N. STOKES.

SiO_2	44.99	MgO	21.02
TiO_2	.97	K_2O	.74
Al_2O_3	5.91	Na_2O	.91
Cr_2O_3	.25	H_2O 110°—	.63
Fe_2O_3	3.42	H_2O 110°+	3.19
FeO	8.30	P_2O_5	.05
MnO	trace	CO_2	trace (?)
NiO	none		
CaO	8.79		99.17

[1] Italian Petrological Sketches, 4, The Rocca Monfina Region, by H. S. WASHINGTON, JOUR. GEOL., Vol. V, 1897, p. 254.

Chemical relations of the series.— In the preceding pages the mineralogical evidence has been given of the variations under discussion. In the following tables there are reproduced the analyses which have been given of the typical members of the different classes. They are arranged in order of diminishing acidity. In Table I the complete analyses are given.

I.

	1	2	3	4
SiO_2	58.51	49.80	48.17	44.99
TiO_2	.72	.79	1.00	.97
Al_2O_3	16.32	19.96	25.26	5.91
Cr_2O_3	none			.25
Fe_2O_3	2.11	6.32	1.13	3.42
FeO	4.43	.49	6.10	8.30
MnO	trace	——[1]	——[1]	trace
NiO	none	——	——	none
CaO	3.92	11.33	9.53	8.79
MgO	3.73	7.05	4.22	21.02
K_2O	4.08	.61	.73	.74
Na_2O	3.11	2.22	1.34	.91
H_2O at 110°	.23	100°— .13	100°— .19	110°— .63
H_2O above 110°	2.00	100°+ 1.71	100°+ 2.00	110°+ 3.19
P_2O_5	.30	.07	.07	.05
CO_2	none	.15	.43	trace?
	99.46	100.63	100.17	99.17

II.

PERCENTAGES OF CHIEF OXIDES REDUCED TO 100.

	1	2	3	4
SiO_2	60.36	49.80	49.41	47.33
TiO_2	.75	.79	1.02	1.02
Al_2O_3	16.83	19.96	25.96	6.22
Fe_2O_3	2.17	6.32	1.16	3.60
FeO	4.57	.49	6.25	8.73
CaO	4.04	11.33	9.77	9.25
MgO	3.85	7.05	4.32	22.11
K_2O	4.21	.61	.74	.78
Na_2O	3.21	2.22	1.37	.96

[1] MnO, etc., not looked for.

III.

ATOMIC PROPORTIONS OF METALS.

Si	55.85	46.53	45.90	42.48
Ti	.53	.56	.72	.70
Al	18.41	22.03	28.50	6.60
Fe	5.08	4.83	5.70	9.02
Ca	4.04	11.42	9.79	8.98
Mg	5.32	9.85	6.01	29.67
K	4.99	.74	.89	.91
Na	5.78	4.04	2.49	1.67

In Table II there is given the percentages of chief oxides reduced to 100, and in Table III the atomic proportions of the metals.[1] The analyses show that all of the rocks contain a moderately large amount of water. Nevertheless, they are sufficiently well preserved to warrant a discussion of their analyses for classificatory purposes. Indeed, No. 4 is remarkably fresh for so basic a rock. With reference to analysis No. 1, it may be stated that the rock is, on the whole, one which it is somewhat difficult to place definitely in the existing division of rock families. The large amount of lime and relatively low percentage of alkalies prevent placing the rock with the syenites, which possibly the presence of the large amount of orthoclase might lead one to do if the rock were studied with the microscope alone. On the whole, it approaches close to the monzonites, according to their chemical composition as given by Brögger.[2] From this it differs, in that the lime, 3.92 per cent., is too low to bring the rock within his limits, 4.52 to 10.12 per cent. However, if we consider the total of the alkaline earths, 7.55 per cent., in this rock, we find that it comes well within Brögger's range, 6.05 to 17.52 per cent., for a total of magnesia and lime. Moreover, the alkali total, 7.19 per cent., is too high to warrant its classification in the monzonite class as a representative of the type of the biotite-monzonite.

[1] These tables were calculated for me by Mr. V. H. Bassett, assistant in chemistry in the University of Wisconsin.

[2] Op. cit., Part II, p. 51.

On comparing the analysis with that of a normal diorite, we find the relative proportions of the alkalies are abnormal. Also the lime content is too low for rocks of this character; and, again, the magnesia is too high. From the above considerations it seems clear that the rock is related to the monzonites and diorites. However, it is so intimately associated with, and so evidently a facies of the tonalite, which is the dominant type where the mica-diorite occurs, that it is considered to be more closely related to the lime-soda-feldspar rocks in which the orthoclase is but accessory, than to the monzonite family of orthoclase-plagioclase rocks. It is, therefore, considered to be a mica-diorite. It has already been remarked that while for normal diorites the lime is too low, the magnesia is correspondingly too high. May we not with right consider this as indicating a relationship to the more basic rocks gabbros, in which magnesia forms a very important constituent and with which it is so intimately associated in the field? As against this interpretation, however, we have a very high percentage of alkalies and moderately high percentage of silica, which certainly warrant the exclusion of this rock from the gabbro family.

When we turn to a consideration of the gabbro-norites as represented by analyses Nos. 2 and 3, it is at once clear that if we accept, as has been done in the preceding pages, Brögger's[1] characterization of the diorite and gabbro families, that these rocks could not be included with the diorites as respectively normal diorite and bronzite-diorite, but must, from their abnormally low silica and alkali content and high alumina, lime, and magnesia content, be placed with the gabbros. Especially noteworthy in analysis No. 2 is the high percentage of alumina present. Normally, large alkali content accompanies high percentage of alumina. A reference to the alkalies shows this not to be true in this instance.

Analysis No. 4 is not to be taken as representing the most basic variety of peridotite in this district. From this alone the statement that the variations extend to the ultrabasic rocks

[1] Op. cit., Part II, pp. 35, 39.

would hardly be warranted. As has already been said, however, the rock of which the analysis was made is one which is feldspathic, and represents a transition upward into the gabbro.

Examining the series of analyses together, we see that in passing from the most acid to the basic end the alumina increases very rapidly to 25.96 per cent., until it reaches the extreme basic rock, when it drops suddenly to 6.22 per cent. The analyses also show an increase in the same direction in iron, as is best brought out in Table III. The alkalies increase with diminishing silica, whereas the magnesia, which for rocks of this character is very characteristic, shows a decided increase. In the gabbro-norite-peridotite portion of the series, analyses Nos. 2, 3, and 4, the lime shows a constant diminution, corresponding to the increasing magnesian character of the rocks. Likewise the potash increases as the soda diminishes. The rocks represented by the analyses are believed to belong to a series ranging from a diorite on the one hand through hornblende-gabbro and norite to a peridotite on the other. It is evident that a gap exists between the gabbro and diorite. The diorite represents a gradation towards the orthoclase rocks of essentially the same acidity. On this acid side of the series the microscope also shows variations to a tonalitic and even granitic rocks very rich in quartz and orthoclase, probably very much more acid in character than the diorite represented in the analyses.

Relations of the rocks of the series.—The rapid changes in mineralogical composition and texture in a single rock exposure, and the changes thus occasioned from one type into another through intermediate facies, show very clearly the intimate relationship of the Crystal Falls rocks to one another, and warrants the assumption that they all belong to a geological unit, a conclusion long since reached by Williams[1] for a similar group of rocks, "The Cortlandt Series" from New York. Variations very similar

[1] The peridotites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS, Am. Jour. Sci., Vol. XXXI, 1886, pp. 26–41.

The norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS. Am. Jour. Sci., Vol. XXXIII, 1887, pp. 135–144, 191–199.

to those here described have been well described by Messrs. Dakyns and Teall from some Scottish plutonic rocks.[1] The field studies have shown the relations of the various members of this series from Crystal Falls to be as follows: The diorite is found cutting the hornblende-gabbro. The gabbro is also found to be cut by a dike of biotite-granite. The relation of this particular dike to the diorite could not be determined; therefore it has not been described. In one case, however, a dike cutting a gabbro showed biotite-granite as a facies of the diorite. It is probable that the other dikes of biotite-granite occurring in the area are facies of the same widely distributed diorite magma. The hornblende-gabbro is cut by the bronzite-norite and the peridotite. It is thus evident that the eruption of the hornblende-gabbro was followed by that of a peridotite on the one hand and by a diorite, possibly even a granite, on the other.

It is a difficult matter to estimate quantitatively the amount of the one or the other rock type present in the Crystal Falls district. We are thus prevented from drawing from the predominance of the one kind or the other the conclusion that those represented in the minority are the results of the differentiation of a magma most nearly resembling in its original constitution that which predominates. Moreover, since the analyzed rock types were not selected as representatives of the extremes of the process of differentiation, it would not be wise to endeavor to give the mean composition of the parent magma, from the analyses of the differentiation products which have been presented. The main thesis, however, seems to be established that the separation of a magma into the various products described has taken place, as is indicated by the relations in the field, and as has been shown by the microscopical and chemical analyses.

From the relations described as existing between the various

The gabbros and norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. Williams, Am. Jour. Sci., Vol. XXXV, 1888, pp. 438–448.

[1] On the plutonic rocks of Garabal Hill and Meall Breac, by J. R. Dakyns, Esq., M.A., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S., Q. J. G. S., Vol. XLVIII, 1892, pp. 104–121.

kinds of rocks, it was seen that the hornblende-gabbro was unquestionably the one which first reached its present position. Whether this is to be regarded as itself representing the composition of the parent magma, or only as a differentiation product of a still deeper seated igneous mass, cannot of course be determined. Be that as it may, the fact, which has been proven, remains, that given the period of eruption of this hornblende-gabbro as a starting point, and possibly this magma as the original one, the forces of differentiation have been active in two directions, towards increasing acidity and increasing basicity, in agreement with the law of succession of igneous rocks as propounded by Iddings.[1]

J. MORGAN CLEMENTS.

[1] The Origin of Igneous Rocks, by J. P. IDDINGS, Bull. Phil. Soc. Wash., Vol. XII, 1892, p. 145.

Studies for Students.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

The object of these studies is in no wise to attempt to furnish a course in vertebrate palæontology, but rather to place before the student of geology, who has no time for the study of the morphological and phylogenetic questions involved, a brief statement of the results achieved by the workers in the more narrow field. The value of vertebrate remains as indicators of the time changes in the past is so well recognized that it is hoped that an orderly summary of the fossil vertebrates, with a brief indication of the lines along which they have developed, and references to the most helpful literature, may be of value to the student, both within the limits of these articles and in aiding him to extend the work by collateral reading.

PART I. THE FISHES.

FISHES are, in the popular language of Bashford Dean, "back-boned animals, gill-breathing, cold-blooded, and provided with fins." This definition may well be used if we remember that the "back-bone" is not always bony, that it may be entirely cartilaginous or only partly ossified. A similar condition may be found in all the other bones of the body and is the chief reason that the early history of the fishes is hidden in the deepest obscurity, for it is one of the most commonly recognized facts of palæontology, as well as one of the most deplorable, that only under the most favorable conditions can the soft structures of any body be preserved. From this it is easily understood why the earliest remains of fishes that we possess are those of forms in which the skeleton has progressed so far as to be formed of solid cartilage at least, and generally of cartilage with local ossification or calcification.

The following classification of the larger groups of the fishes is in general use :

Class : PISCES.
- Sub-Class : *Marsupiobranchii.*
  - *Ostracodermi.*
  - *Elasmobranchii.*
    - Order : *Selachii.*
      - *Batoidi.*
- Sub-Class : *Holocephali.*
  - *Dipnoi.*
    - *Sirenoidei.*
    - *Arthrodira.*
- Sub-Class : *Teleostomi.*
  - Order : *Crossopterygii.*
    - *Actinopterygii.*
      - Sub-Order : *Chondrostei.*
        - *Teleocephali.*

The first of these, the *Marsupiobranchii*, are not well understood in their relations to the true fishes. The most common of the group are the hagfishes and the lampreys of the present time. They differ from all other vertebrates by the entire absence of the lower jaw and of the pelvic and pectoral girdles of bone that support the hind and the fore limbs. Whether these conditions are the primitive stages of a developing fish or are the final stages of a degenerate structure, is still an unsettled question, and it is at this point of difficulty that we turn to the palæontological record. However, we can gain but little from the palæontology of the forms. A single specimen from the Old Red Sandstone of Scotland is the representative of the fossil *Marsupiobranchii*, and it is even doubtful whether this specimen is correctly referred to that group. The specimen shows the presence of well defined rings in the position of the vertebræ, a stage in advance of the recent forms, which would indicate for them a degenerate structure.

The earliest remains of fishes known are from the Lower Ordivician rocks of the Grand Canyon region of the United States. These are the very imperfectly preserved remains of what seem to be scales and bones of fishes whose affinities cannot be made out from the material.

Before attempting to take up the different forms of the true fishes it may be well to consider briefly those points in the anatomy of fishes in general where changes have taken place resulting in the modern type of the bony fishes. There are three regions in the skeleton that have been used more than any others in making out the different groups of the fishes and their phylogenetic development: 1. The gradual ossification of all the bones of the body. 2. The development of the vertebræ. 3. The development of the fin of the modern type.

The first of these is the gradual process of strengthening the skeleton by the addition of solid matter which has been at work ever since the origin of the class and is still incomplete in many forms. It is only in the last sub-order of the *Teleostomi*, the *Teleocephali*, that the process is at all complete. Before the actual formation of bone in the supporting tissues of the body the cartilage was frequently strengthened by the deposition of calcareous particles. This is the condition found in the remains of most of the early sharks.

The second process, the development of the vertebræ, is of considerable importance not only in the development of the fishes, but as we shall see, in the earliest of the *Amphibia* as well. The most primitive condition of the spinal column is such as is well illustrated in the *Amphioxus*, one of the simplest of all the vertebrate phylum, the column in this case consisting of a continuous rod of cartilage, the notochord, extending through the body from the anterior to the posterior end and lying near to the dorsal side of the body. It is protected by several layers or sheaths of membrane in which the future vertebræ are developed. The development of the bony covering of this rod is foreshadowed by the appearance of the cartilaginous rings that have the same serial arrangement as the vertebræ of the more advanced types. A very important thing about the development of the vertebræ is the development on the superior and the inferior faces of the chordal sheath of bony arches that appear before the body proper, or centrum, of the vertebræ. The superior of these, the neural arch, protects the spinal cord throughout the length of the vertebral column. The second is developed to the fullest extent only in the caudal portion of the column and there furnishes a protection for blood vessels. These arches may or may not be attached to the centrum in the adult form, but the bases are the first points of ossification and the rest of the vertebræ develops between them. The process is not complete in all of the fishes, and the gradual completion of the vertebræ is of great aid in determining the position of some of the fossil forms (Fig. 1).

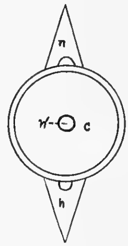

Fig. 1. Schematic view of a vertebra. *n*, neural arch; *c*, centrum; *h* hæmal arch; *w*, notochordal canal.

The third, and perhaps the most important of the three regions of development is the formation of the fins, both paired and median. Whatever may have been the original form of the fish the first thing in the evolution demanded by their peculiar environment must have been the development of some form of keel that would not only aid the fish in its progress through the water, but would enable it to maintain any desired position both as to the relative depth below the surface of the water and as to lateral displacement. The first step in the accomplishment of this end was the development of long fins extending from the head to the tail. One pair of these was developed on the median dorsal and ventral lines, and persists in the dorsal, caudal, and ventral fins of the existing fishes. The second pair extended along each side of the body in a plane at right angles to the first and divided the body into approximately equal parts above and below. The paired fins, the pectoral and the ventral, are supposed to be remnants of these lateral folds or fins.

The development of the fins seems to have followed a very definite line that has served as a great aid in making out the classification of the various fossil and recent forms. Undoubtedly the first stage of the development of the fins was the formation of the long folds of the skin that were without any internal support, and capable of very complex, wavelike motion, and without any great power of resistance to impressed forces. Of this stage we do not have any trace in the preserved fossil forms for the reason already assigned, that soft parts are not preserved except under the most exceptional circumstances. We should expect it to occur in the remains of the *Marsupiobranchii*, if at all, but the single specimen preserved, *Paleospondylus*, does not show any evidence of such a fold. The function of the fin fold, to preserve the equilibrium of the fish, would demand some degree of resistance in the fold, and the next stage of the fin must have been the appearance of fine, hair-like rays of horny material, confined to the dermal part of the fold and not joined to the body proper. These were many in number, and only served to stiffen the fin without strengthening its attachment to the body. These fine rays have been called the actinotrichia. The second stage in the development of the fins was the fusion of certain of these actinotrichia at points of the greatest strain in the fins into larger and more solid elements that afforded a much greater power of resistance at those points. The comparatively large and strong cartilaginous rods thus formed have received the name of radials. The same necessity of resisting outside forces that caused the union of the actinotrichia to form the radials demanded a stronger attachment of the radials to the body wall of the fish, and this was accomplished by the separation of the proximal portion of the radial as a separate element, which became elongate and penetrated into the body wall, affording a very strong support to the radials. This proximal section is called the basal (Fig. 2).

Up to this point in the development of the fins the history of the paired and the unpaired fins is regarded as practically the same, for the paired fins were as yet but undifferentiated parts of the lateral body folds. The reason for the development of one portion of the lateral fins over another is not well understood, but it has been suggested that at points of especial strain in the fold, points where, from the mechanical advantage of their

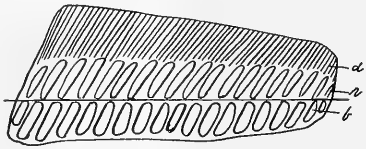

FIG. 2. Schematic unpaired fin; *b*, basal, *r*, radial; *d*, dermal margin of fin (after Smith-Woodward).

position, certain parts of the fold were able to assist in the propulsion of the body through the water, that the fins were especially well developed, and that there appeared lappetlike prominences in the position of the present paired fins. As these lappets assumed more and more of the function of swimming organs, and less of balancers, they required an even stronger support than before, and this was accomplished by the fusion of the basals together and also of the radials, though to a less extent. As the lappets of the lateral fin grew in importance, the intermediate portion dwindled away until all trace of the original fold is lost between and beyond the paired fins. The final step in the development of the fins was the appearance beyond the distal ends of the radials of fine dermal elements that have much the appearance of the original actinotrichia. These serve the purpose of supporting the web at the extremity of the fins.

Another line of development of the fishes is closely allied to the development of the fins. The median fin that originally extended from the head of the animal to the tail has in the course of its development gradually retreated toward the posterior portion of the body until it is represented by a single caudal fin and one or more separated elements called from their positions the dorsal and the anal fins. The caudal fin has assumed different positions in relation to the terminal portion of the spinal column. In the original condition the dorsal and the ventral parts of the fin were equally developed, and the vertebral axis divided the fin into two equal parts, so that the fin presented a rounded or slightly acuminate appearance. This is called the diphycercal condition. Another, and a very common condition among the more primitive forms of fish, is where the ventral portion of the caudal fin is developed at the expense of the dorsal, and the terminal portion of the vertebral axis is bent upward at the end. This is called the heterocercal condition. The form most commonly found in the modern forms of fishes is that in which both the dorsal and the ventral portions of the caudal fin are developed more than the main portion of the fin, but about equally themselves. This is called the homocercal condition, and was for a long time considered as the primitive condition, or at least more primitive than the heterocercal. It is shown to be untrue by the fact that even in the highest types of the bony fishes the extremity of the notochord is bent upward as in the heterocercal form of the tail. The progress of development of the tail seems to have been from the diphycercal through the heterocercal to the homocercal.[1]

The oldest remains of fishes that are definitely known come from the Upper Silurian and the succeeding rocks as high as the Carboniferous. The group called *Ostracodermi* has long been denied a position among the fishes by certain authors, the principal objection being the seeming lack of any lower jaw, which is regarded as one of the principal characters of the vertebrates. Because of this feature and the appearance of some of the forms which is similar in a general way to that of the Trilobites, the group has been considered as belonging to the *Crustacea*, but there are so many other characters that unite them with the

[1] A discussion of the facts here pointed out, with much more that is valuable to the student, will be found in a recent book by Bashford Dean, *Fishes, Living and Fossil,* an outline of their forms and probable relationships, Columbia University Biological Series, Macmillan & Co., 1895. This book takes up the various forms of fishes in a popular way that will not be beyond the student of geology who has the principles of biology. The large number of excellent illustrations will be found to be of great value in getting an idea of the fossil forms.

fishes that no less an authority than Smith-Woodward has placed them among the fishes. In general, the group is distinguished by the fact that the bones are not ossified; that the paired fins and the lower jaw are absent, and that the anterior part of the body is covered by large, bony plates that are developed in the skin and have no connection with the cartilaginous skeleton. The group is divided into three families: *Pteraspidæ*, *Cephalaspidæ*, and *Pterictlhidæ*.

Pteraspidæ.—This family is confined almost exclusively to the Devonian, the Old Red Sandstone of England and Scotland. It contains the simplest and most archaic forms of the *Ostracodermi*. The anterior part of the body was covered by two large plates, a superior and an inferior, that served as a complete armor for that part of the body. The eyes protruded from openings formed by notches in the adjacent edges of the two plates. The upper plate is sometimes marked by grooves that are supposed to indicate the course and distribution of sensory tracts such as are found in the skulls of the shark and many of the more advanced types of fishes. The posterior part of the body was covered by many small rhomboid scales. It is probable that the forms were bottom feeders, and that the common food was the abundant molluscan fauna of the Devonian seas. *Pteraspis* and *Holaspis*, from the Devonian of England, and *Palæaspis*, from the Upper Silurian of Pennsylvania in the United States, are the best known of the family.

Cephalaspidæ.—In many respects the members of this family resemble the last, the anterior part of the body is covered by well developed plates, while the posterior portion is protected by rhomboid scales. The size was, in general, smaller than either of the other families, seldom reaching more than a foot in length. The head was large and curiously like that of a Trilobite in external appearance. The anterior edge was rounded, and there were two lateral posterior extensions in a position analagous to that of the genal spines in the Trilobites. The eyes were located near the center of this plate. The scales that formed the protection of the posterior part of the body are large and arranged in rows, the mid-dorsal row developing an acuminate ridge that has the appearance of a dorsal fin. The tail was distinctly heterocercal. In some of the more perfectly preserved specimens there seems to be an indication of the presence of external gills at the base of the posterior lateral spines of the head plate. All the known forms are from the Upper Silurian and the Devonian rocks of England and Europe. Among the best known of the genera are, *Cephalaspis*, *Auchenaspis* and *Tremataspis*

Pterícthidæ.—This family presents many important steps in advance of the other two, the anterior part of the body is not protected by single plates, but by an armor made up of the union of several small plates both upon the upper and the lower sides. The posterior portion was, as in the other forms, covered with small scales. Perhaps the most peculiar thing about the family is the presence upon the sides of the body, near the anterior end, of elongate, movable appendages that perhaps served as swimming organs, although in one of the later and more specialized of the forms the appendages become anchylosed to the adjoining plate, and lose all power of motion. These appendages are regarded as the homologues of the posterior extensions of the head plate of the *Cephalaspidæ*. The *Pterícthidæ* are most commonly known from the Devonian of the Old World. *Pterícthys*, *Asterolepis*, and *Bothriolepis* are well-known European forms. From the New World *Bothriolepis* has been described from the Devonian of Canada, and from the same horizon in Ohio incomplete remains have been described by Newberry as *Acanthaspis* and *Acantholepis*. It is necessary here to warn the student against a confusion that may arise between the old classification present in so many of the text-books and the one here used. The *Pteraspidæ*, *Cephalaspidæ*, and the *Placodermi* were regarded as orders of the highly artificial group, *Ganoidei*. The last order included not only the *Pterícthidæ*, but more highly developed forms that are now known to belong to the *Dipnöi*.

The *Elasmobranchii* are the most primitive forms that hold an undisputed position among the fishes. Including both the sharks and rays, the group may be defined as made up of forms in which the skeleton is cartilaginous, the skin filled with fine calcareous particles (shagreen), the tail heterocercal, and the external openings of the gills mere slits in the skin of the neck unprotected by an operculum. In the previous sub-class there are no remains preserved of distinct vertebræ, but in the sharks the beginning of the vertebræ is seen in the formation of cartilaginous rings in the sheath of the notochord. These rings are of varying degrees of development in the different forms, in some forming mere circular bands around the chord, while in others they are nearly closed by the ingrowth of the cartilage that tends to segment the chord off into intervertebral elements. There is always attached to the superior and the inferior faces of the cartilaginous ring the neural and the hæmal arches that carry the spinal cord and the blood vessels.

The most primitive of the fossil sharks comes from the Lower Carboniferous of Ohio. This form, *Cladoselache*, is, in many respects, quite close to the hypothetical type form of all the fishes, the body is long and slender, and there were seven gill slits in the neck, which seems to be the number characteristic of the earliest forms. The unpaired fins have not progressed beyond the second stage of development, as outlined in the first part of this paper, that is, the fin fold is supported by small rods of cartilage, radials, that are not attached to the body wall. The paired fins are in a scarcely more developed condition, the lateral fold has disappeared, but the two lappets that represent the pectoral and the ventral fins have not progressed beyond the stage of the radial support, and are consequently of no value to the fish as swimming organs, but must have served merely as balancers. The tail was abruptly heterocercal. The whole form was rather small, not reaching a length of more than six feet at the outside.

Acanthodes, a rather small form from the Coal Measures of England, seems to present a step in advance of *Cladoselache*. The shagreen particles that are scattered throughout the skin of most of the sharks are in this form enlarged into scalelike forms that fit tightly one against the other and afford a complete cover for the body. The paired fins are more strongly developed than in the previous form, and are better fitted for the purpose of balancing the body as well as assuming, to some slight extent, the function of locomotion.

Climatius, from Devonian Old Red Sandstone of Scotland, is of considerable interest from the fact that between the paired fins on the two sides there are developed many smaller fins, located along the line of the primitive fin fold. These are regarded as the remnants of the disappearing lateral body fold. The form represents a stage in this respect ancestral to both *Cladoselache* and *Acanthodes*, but is in other respects in advance of both of them.

Pleuracanthus, from the Permian, is one of the most interesting of the fossil sharks. It represents a stage considerably in advance of the forms already described. The radials of the median fins have separated off the proximal basal segments that afford the strong attachment of the fin to the body wall, and there is developed to some extent the dermal elements of the external edge of the fin that are found in the fins of the modern bony fishes. The paired fins present a very interesting condition, the fore limb having the character of a dipnoan fin, and the hind limb the characters of the more advanced type of the fish fin. To understand this condition it is necessary to go back to the formation of the paired fins from the lateral fin folds. The gradual development of the functional swimming fin was by the concresence of the basal and the radials to form strong, though somewhat flexible supports for the membrane of the fin. This was accomplished in two ways. In one the basals united and formed a long median axis upon each side of which the radials were attached after the manner in which the barbs of a feather are attached on each side of the quill. This type was originally supposed to be the most primitive form of the fin, and so it was given the name of *archipterygium*. In the other type the basals fused into one or more pieces that were confined to one side of the fin, and the radials formed the other side; this is the type of fin present in the more advanced fishes; it is called the *ichthyopterygium*. See Fig. 3.

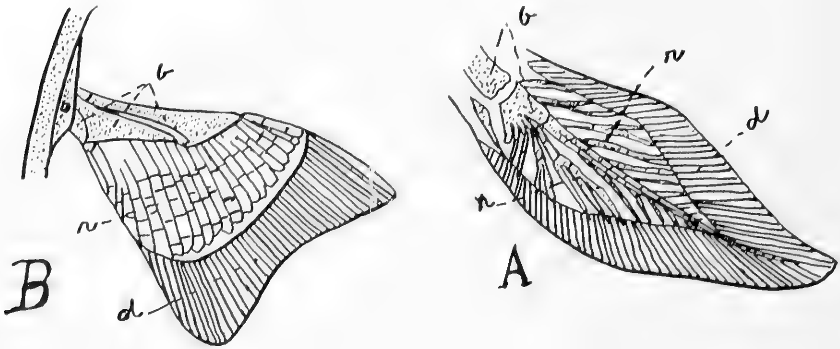

FIG. 3. *A*, archipterygium; *B*, ichthyopterygium; *b*, basals; *r*, radials; *d*, dermal margin.

Besides the peculiar condition of the fins, *Pleuracanthus* presents other remarkable features. Notable among these are the presence of a large spine that projected from the posterior edge of the skull, and the fusion of the shagreen denticles on the superior surface of the head into numerous dermal plates. In *Pleuracanthus*, as well as the forms previously mentioned, the center of the vertebræ had not yet become very well developed, and all that is found in the preserved specimens is the line of neural arches above the position of the notochord and the hæmal arches below.

Chondrenchelys from the Carboniferous of Europe was in many respects similar to *Pleuracanthus*, but there is one point of decided advance, the vertebræ were well formed, though still cartilaginous, and the inner part of the cartilaginous vertebral ring was well filled so that the chord was divided into segments by constrictions at the center of the vertebræ.

With the appearance of the sharks of the type of *Chondrenchelys*, the modern form is outlined, and since the Carboniferous there has been no great change in the general structure of the group. One thing is important, however, and that is the changes that took place in the teeth of the many forms that were developed during the Carboniferous time. There seems to have been developed two types of teeth that indicate a very different mode of life. In one of these groups the teeth became flattened and adapted to crushing or grinding the shells of molluscs and crustaceans that formed the food supply. The surfaces of the teeth were sculptured in the most intricate manner, affording an enlarged and more efficient triturating surface. The different patterns of this sculpture seem almost endless. To these forms have been given the name of the "pavement-toothed sharks." *Janassa*, *Petalodus* and *Cochliodus*, all from the Carboniferous rocks are perhaps the best representatives of the group. *Cestracion*, the modern Port Jackson shark, is the single living representative. In the second group the teeth were developed in accordance with the demands of a more active and rapacious habit. They are more or less triangular in outline, and the edges are frequently finely serrated, affording a very firm hold as well as forming most efficient cutting organs. This type reached its development later than the pavement-toothed forms. The largest form, *Carcharias*, in which the teeth reached a length of six inches, is known from the Eocene of both the Old and the New Worlds. Other typical forms are *Sphenodus*, *Lamna*, and *Carcharodon* from the Mesozoic of Europe and many forms that are regarded as subgenera of *Carcharias* in North America.

One type of fossil that must be mentioned is the *Ichthyodorulite*. These are detached spines that are found in great abundance in the Carboniferous and Mesozoic rocks, and from which a large number of genera have been named. In the modern sharks the anterior end of the fins, and especially the dorsal fin, is frequently strengthened by the development of a strong spine that serves as a cutwater. These spines were much more strongly developed in the more primitive sharks, and were subject to the greatest degree of modification in form, structure, and ornamentation. As they were so strong they would naturally be preserved through the accidents of fossilization more often than the softer structures of the skeleton.

The Rays or *Batoid* branch of the *Elasmobranchii* are of doubtful origin, other than the fact that they differ from the true sharks only in the modifications that are attendant on the extreme flattening of the body due to the habit of bottom feeding. They probably originated as far back as the Carboniferous time, although well-preserved forms are not known from rocks earlier than the Jurrassic. *Rhinobatis*, an existing genus, is known from the Oolite.

The part played by the sharks in the waters of the Palæozoic oceans seems to be very much the same as that played by the recent bony fishes in the modern waters. The variety of forms was seemingly endless, and the adaptations to various conditions of life, and to different means of obtaining food, bear witness, not only to the large number of forms, but to the strength and dominance of the type.

The *Holocephali*, the Chimeroids, is a peculiar, aberrant group, that is allied on the one hand to the sharks and on the other to the Dipnoans. The structure of the fins and the vertebral column is the same as in the sharks, but the structure of the head and the arrangement of the teeth is almost the same as the dipnoans. There is a single broad dental plate in the lower jaw, and two plates in the upper jaw instead of numerous isolated teeth. The surface of these tooth plates is variously modified by the addition of knobs, ridges, and other irregularities, to increase the grinding surface. Little is left of the fossil forms but the teeth and the spines that stood at the anterior end of the dorsal fin as in the sharks. Fossil forms are *Ischyodus*, *Myriacanthus*, and *Squaloraja*, all from the Mesozoic.

The *Dipnoi* are, perhaps, the most peculiar of all of the fishes. For a long time considered as the linking type between the fishes and the amphibians, they are now generally regarded as a degenerate group that originated from the stem of the Crossopterygian *Teleostomes*. They are characterized by the absence of a connecting bone, the quadrate, between the skull proper and the lower jaw. This condition, called autostylic, is found in the preceding group. Other characters are the modification of the swim bladder, in the living forms at least, as a breathing organ that assumes to some extent the structure of the lungs of the land vertebrates, the presence of tooth plates instead of teeth in the jaws, the archipterygial structure of the fins and the diphycercal tail. At the present time there are only three genera of the group living, but their wide distribution points to a very great development in earlier times. The existing genera are *Protopterus* from Egypt, *Ceratodus* from Australia, and *Lepidosiren* from South America. In these forms, as in the fossils, the vertebræ are incompletely ossified, the centrum remaining cartilaginous, while the upper and the lower arches are fairly well ossified. The major portion of the skeleton is well ossified, thus showing a condition in advance of the sharks and Chimeroids.

The *Dipnoi* are an exceedingly ancient group; even as early as the Devonian they had developed most of the characters that distinguish them from the other fishes. While it is altogether probable that they originated from the primitive shark stem, the point of origin seems to be totally lost, for the well-developed Dipnoans are found contemporaneous with the earliest of the sharks. Of the early *Dipnoi*, perhaps the most interesting is *Dipterus* from the Old Red Sandstone. This form had well-developed cycloidal scales, the type of the modern fish scale, while the sharks still had the shagreen denticles, and the Ostracoderms the thick, bony, rhomboid scales so characteristic of the early fishes. It had the skull protected by a roofing of dermal plates, and the teeth modified into large plates, with rough triturating surfaces. The plates were arranged as in the *Holocephali*, two in the upper jaw and one in the lower jaw of each side.

Phaneropleuron, from the same horizons in Scotland, is more primitive in some of the characters; for instance, the jaws are provided with many small, conical teeth, and the dorsal fin is continuous instead of being broken up into two or three segments. Specimens of this genus are known from the Devonian rocks of the province of Quebec in Canada. *Ctenodus*, from the Carboniferous of England, *Holodus* and *Palædaphus* from Devonian of Europe, *Mylostoma* from the Devonian of New York, and *Gnathorhiza* and *Strigilina* from the Permian of Texas, are all characteristic forms that have been described from the teeth.

A division of the *Dipnoi*, the *Arthrodira* are of especial interest, as they were at one time regarded as belonging with the *Pterichthidæ* in an order the *Placodermi*. The discovery of well-developed lower jaws and paired fins demonstrated that they could not belong among the primitive *Ostracodermi*, and the discovery of the manner of the articulation of the lower jaw to the skull showed that they belonged among the *Dipnoi*. They are among the most ancient of the fishes, ranging from the Upper Silurian to the Carboniferous. In the United States a large majority of the known remains have been taken from the Waverly Shales of Ohio. In Europe they are found in the Devonian Old Red Sandstone of England and Scotland. They were powerful, armored, predatory forms, in many cases of large size, that must have been a match for the largest sharks of the time. The armor in some of the genera was between two and three inches in thickness. The armor seems to have been confined in most of the forms to the anterior portion of the body, which has led to the belief that perhaps they buried the posterior part of the body in the mud and lay in wait for their prey rather than seeking it out and depending on their rapidity of movement and powerful jaws to obtain the mastery.

Coccosteus, a rather small form from the Devonian of England, is one of the best known of the group. It did not reach a length of more than one or two feet. The anterior part of the body is covered with an armor made up of several plates that extend back to about the middle of the body. The centra of the vertebræ are not preserved but the upper and lower arches outline the notochordal column. The dorsal fin is in the stage of the basals and radials and the posterior pair of fins is united to a distinct pelvic girdle. The armor of the anterior portion of the body was very hard and polished in appearance, looking like the enamel scales of the "Ganoid" fishes and covered with small tubercles that were divided by the course of rather deep sensory canals. The armor plates were purely dermal in character having nothing to do with the true skeleton which was still made up of cartilage. One very peculiar thing was the presence of a very strong joint between the plates covering the head and those covering the shoulders. This joint must have permitted a great degree of motion in the vertical direction between the head and the body, though the purpose of such a motion is not understood. The posterior part of the body was covered by a thick integument entirely devoid of scales such as are present in the *Ostracodermi.*

The American forms of the *Arthrodira* were in general much larger and better developed than the European ones. They reached a total length of as much as ten or twelve feet and the sculpture of the armor and the variety of forms presented in the development of the jaws bear witness to the great variety of genera developed. The arrangement of the teeth is somewhat as in the Dipnoans, that is there were no separate teeth bordering the jaws but there were dental plates that were attached to the edges of the jaw; one peculiar thing about the plates is that they were not fixed as in the Dipnoans but were to a greater or less extent movable. In general the body form was like that of *Coccosteus* but the modifications of the tooth plate presents a very remarkable series. In *Dinicthys* they are developed as sharp cutting edges with a strong notch near the anterior end, in *Titanicthys* as a simple cutting edge, in *Trachosteus* and *Diplognathus* the edges of the plates were serrated and presented the appearance of being set with isolated teeth as in the ordinary arrangement of the fish jaw.

The last of the subclasses of the fishes is the *Teleostomes.* This group includes the old orders *Ganoids* and *Teleosts* that have been used for so long and are still commonly met with in the text-books of geology. The main distinction between them as seen by the geologist is the presence in the Ganoids of bony, rhombic scales and in the Teleosts of horny, cycloidal scales. It is readily shown that these characters are of the most superficial nature and the condition of one group is easily found in the other, still as a general thing it may be said that a majority of the older forms had the rhomboid type of scale and the modern forms have the horny type. Bashford Dean discusses the relationships and descent of the Teleostomes in the following words, p. 145: "Johannes Müller, when separating Ganoids from Teleosts, recognized clearly even at that early date (1844) that the majority of the structural differences of these forms were bridged over in exceptional instances; there were thus Teleosts with bony body plates, as well as, it was afterwards found, a Ganoid, (*Amia*) with herringlike cycloidal scales. But he believed that three structural characters of the Ganoids separated them constantly from all Teleosts, and warranted the integrity of the groups."

These distinguishing characters were:—

I. A contractile arterial cone, containing rows of valves.

II. An intestinal spiral valve.

III. The interfusion (chiasma) of the optic nerves.

It was not until these differences were shown to be of little morphological importance that the two groups were merged in that of the *Teleostomi* (Owen, 1866). Thus transitional characters of the arterial cone of *Butrinus* were discovered by Boas. The Teleost, *Cheirocentrus* was found to present Ganoidean intestinal characters, and the optic chiasma, as Wiedersheim demonstrated, could no longer be regarded as of taxonomic or morphological value.

The descent of the Teleostomes, like that of the other groups, has long been a matter of speculation. Their affinities with the Dipnoans are generally admitted (Gunther, Gegenbaur, Haeckel, Smith-Woodward). Rabl derives them directly from a Selachian stem, regarding the Dipnoans as later evolved Ganoidean forms. Beard, on the other hand, even goes so far as to entirely separate the Teleostome stem from that of the shark, lungfish, an amphibian, deriving it with a close kinship to the *Petromyzonts* (*Marsupiobranchii*), from the earliest vertebrates. Palæontology, however, has lately been giving rich contributions to this disputed problem, and there can at present be little doubt that the conditions in fossil fishes have demonstrated that in most ancient times Dipnoan and Teleostome were closely approximated. Although even in the earliest fossils they may be distinguished (*e. g.*, by the arrangement of the head-roofing derm bones), yet, as Smith-Woodward has noted, forms occur too clearly transitional to indicate anything less than genetic kinship. The Crossopterygian, whose ancient structure is well known, may well have been derived from an ancestor common to the Ctenodont (Dipnoan) and the Holoptychian; so that the gradual nearing of the Teleostome stem to that more fixed, of the Dipnoan, is a strong suggestion of its derivation. The later descent of the Ganoids from an ancestor closely akin to, if not identical with the Crossopterygian, is usually conceded. Teleosts, first occurring in the Cretaceous, are by evidence of fossils the almost undoubted survivors of an extensive group of transitional Mesozoic Ganoids. But whether all Teleosts are to be deduced from a single ganoidean phylum can at present hardly be established. Thus catfishes, or Siluroids, appear in many structural regards closely akin to the sturgeon; but as their fossil remains are lacking before the Eocene — when however, they appear to have been in every way as highly evolved as in recent forms — little clew has been given to their descent.

Teleostomes may, in the present connection, be briefly characterized in their two principal subdivisions.

I. *Crossopterygian*, the more archaic group, uniting the characters of shark, lungfish, and ganoid, retaining the ancient cartilaginous fin bases, radials, and basals in their lobate fins; in some forms (*Holoptyhchius*), the concrescence of the basal parts of the unpaired fins passing through the same evolution as those of the paired fins. Represented in the surviving *Polypterus* ("*Bichir*" of the White Nile) and in the slender *Polypteroid Calamoicthys* (of Calabar), and in the extinct *Holoptychius, Undina, Diplurus* and *Coelancathus.*

II. *Actinopterygian*, the spine-finned Teleostomes. Fins supported by dermal rays; ancient fin support greatly reduced, implanted in the body wall. Includes *Chondrosteans* (Ganoids) and *Teleocephali* (Teleosts).

Among the fossil forms of the Crossopterygians *Gyroptychius* and *Osteolepis* from the Old Red Sandstone of Scotland are very similar to the early Dipnoans in the general appearance of the body. The tail is somewhat heterocercal and the dorsal fin is divided up into segments; but the teeth are numerous and arranged along the edges of the jaws instead of being reprerented by single plates. The entire body was covered by solid, bony scales the outside of which were covered by a layer of shining enamel. The anterior pair of the paired fins is approaching the condition in the Dipnoans, the archipterygium.

Holptychius, from the same locality and horizon as the last, is peculiar in that even at that early date it had developed the cycloidal, horny scales of the modern fishes, both the anterior and posterior paired fins are archipterygial in structure and the caudal fin has become nearly diphycercal by the fusion around the end of the body of the dorsal fins, the caudal and the anal. *Eusthenerpeton*, from the Devonian of Canada, is very similar to *Holoptychius*.

Diplurus, from Triassic of New Jersey, and *Undina*, from the Jurassic of England, present the last stage in the development Crossopterygians. They show an amount of specialization that indicates the extent to which the group had developed and the necessity for adaptation by its members to the most peculiar conditions to maintain an existence. *Undina* was short and very broad. The tail is especially broad and presented a very peculiar appearance, as the end of the spinal column extended beyond the broad psuedo-caudal fin formed by the posterior dorsal above and the anal below. The centra of the vertebræ are still unossified and the bases of the fins are reduced to single pieces of bone. In both this form and *Diplurus* the air bladder was ossified to a considerable extent so that it is preserved in the cavity of the body. *Diplurus* was greatly shortened in the body by the enormous development of the psuedo-caudal fin, formed as in the case of *Undina* by the posterior dorsal above and the anal below, with the end of the vertebral column extending out beyond the two in a slender fin. The skull was relatively enormous and the jaws entirely edentulous.

Coelacanthus, from the Carboniferous of Ohio, is another of the highly-specialized Crossopterygians. The fins, scales, and general contour of the body is that of a modern bony fish, and it is only upon close examination that the fins were found to be of the archipterygial type and the caudal fin formed in the same way as the same fin in *Diplurus* and *Undina*.

The Actinopterygians are separated into two groups, the *Chondrosteans* and the *Teleocephali*. The first of these groups is very similar in many of its characters to the Crossopterygians, the most important difference and the one that marks the separation of the two greater groups is the structure of the fins. Instead of the lobate, or archipterygial type of fin with the well-developed basals and the symmetrically-arranged radials and fin rays, the basals have almost entirely disappeared and the fin has developed the monoserial structure, *i. e.*, the basal supports are confined to the most proximal part of the fin, and the rays are developed on one side only of the supports.[1] The skeleton is still cartilaginous and the scales are bony and covered with enamel.

Elonicthys, from the Permian of Europe, is a typical one of these forms, the body was somewhat elongate and the scales were narrow. *Eurynotus* from the Calciferous limestone of Scotland, *Cheirodus* from the Coal Measures of Scotland, and *Microdon* from the Jurassic of France, exhibit stages in the gradual development of a great vertical expansion of the body with an attendant shortening and flattening. In the last form there were developed flat crushing teeth instead of the sharp, conical form.

Aspidorhynchus, from the Jurassic of Solenhofen, was an elongate form much like the modern garpike in appearance

[1] See Fig. 3. Ichthyopterygium.

The body was protected by large enameled scales, and the head terminated in a long and sharp rostrum.

Palæoniscus is one the most important of the fossil *Chondrosteans.* It has a remarkable time range extending from the Palæozoic to the Mesozoic and developed a very large number of species. It is supposed to be the form that stands nearest to the ancestral type connecting the modern garpikes and the sturgeons.

These forms seem to have culminated in the modern sturgeons, in which the scales have almost entirely disappeared. In *Acipenser* a few rows of large dermal, enameled plates is all that is left, while in such forms as *Polyodon*, the spoon-billed catfish, the skin is entirely naked.

A second group of the *Chondrosteans*, developed mostly in the Mesozoic, had much more the appearance of the pure bony fish. The scales were small and rounded, and the fins are similar in shape and arrangement to some of the Teleocephali. The bones are calcified and the tail is nearly homocercal, but the vertebræ are still unossified and the notochord is prominent. The modern *Amia*, dogfish, is a surviving member of the group. Among the fossil forms are *Caturus*, *Megalurus*, and *Leptolepis*, from the Jurassic of Solenhofen. The first two of these are important in showing the formation of the vertebræ from the gradual development of bone in the centrum starting from the bases of the upper and the lower arches. In the first two of these forms the base of each arch is joined to a half-moon shaped element that is broad at the base and comes to a point at about the center of the centrum, the two together forming a ring that surrounds the notochord. In *Eurycormus*, from about the same horizon as the last, the same condition prevails in the vertebræ of the dorsal region, but in the tail the wedge-shaped half-moons are completed into bony rings and each vertebra is represented by two of these rings. (A condition that will be found of great interest in the consideration of the morphology of the vertebræ of certain of the amphibia.) The beginning of the process of forming the bony vertebræ by the growth of the peripheral portion of the ring is seen in the more primitive forms, *Microdon* and *Pycnodus*. In the first of these the bases of the arches are expanded and terminate in rounded and flattened processes that cover the sides of the notochord to a considerable extent, but do not meet in the middle line. In the second form the bases of the arches are more expanded than in the first and the edges of the expanded portions are serrated so that they interlock both with the ones immediately before and behind them and with the one on the opposite side of the notochord.

There have been mentioned here, of course, only the forms that show to some extent the modifications and the lines of development along which the Ganoids traveled. The waters of the Mesozoic lakes and oceans were swarming with members of the group that presented almost as many varieties of structure and form as do the modern bony forms. Because of the strong, interlocking, enameled scales the whole body of the fish is commonly preserved, but the internal skeleton is much less commonly available, so that the most of the forms are known from characters of the scales and the position of the fins, both of which characters are, to a certain extent, unsatisfactory and unreliable.

The *Teleocephali*, the group generally known as the Teleosts, seem to have appeared at about the beginning of the Mesozoic time though it did not reach a great degree of development until near the close of that period and during the Tertiary time. The members of this group differ from the other forms of fishes in the complete calcification of the bones of the body and the nearly complete loss of the notochord by the development of the solid vertebræ which divides it up into intervertebral segments. The scales are horny and rounded, loosely attached to the skin and overlapping in the style of shingles. The fins are formed almost entirely by the dermal fin rays, the basals, and the radials being greatly reduced. Dean says, p. 167: "Fins are dermal structures, their ancient basal supports hardly to be distinguished; the primitive tail structure is so masked by clustered and fused elements that its heterocercy is scarcely apparent. In short, the most widely modified conditions can be shown to exist in Teleosts in almost every structural character, as in gills, teeth, opercula, circulatory and urogenital organs, sensory structures and nervous system. They have evidently been competing keenly in the struggle for survival, for in every detail of form or structure the most varied conditions exist. In addition to these structural adaptations of the Teleosts, changes in coloration have been rendered possible by the transparency of their scales; and in their different families these changes have taken place often with striking results." It is impossible to go into the forms of the *Teleocephali*, for they are so many and varied that there is no outline even, that the limits of the purpose of this paper would permit. A study of the fossil Teleosts would be practically a study of the osteology of the recent forms.

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E. C. CASE.

EDITORIAL.

Editors Journal of Geology:

My attention has been called to a footnote, appended by one of your number, to a notice of mine, relating to Zirkelite, which note reads as follows: "The prior use of the name *Zirkelite* is certainly established, but it is a question how far a petrographer is justified in stigmatizing the name of a fellow-worker by attaching it to an indefinitely decomposed and ill-defined rock." (JOURNAL OF GEOLOGY, 1898, Vol. VI, p. 200.)

It would seem but common courtesy for another "fellow-worker" to ascertain the truth of his words before he takes advantage of his editorial position to publicly brand another as guilty of an action so low that it ought, if true, to forever ostracize him. I have differed on some points from Professor Zirkel, although in far many more I agree with him. It would seem that my writings prove that I have the courage to openly and honorably express my convictions, and that I do not have to resort to any such vile and disreputable tricks as that your associate plainly but falsely charges me with. I should despise myself if I did, and should expect to be shunned by all decent men. My warfare has ever been open, frank, and honorable, and I have never descended to personal spite and secret efforts to injure another. My contentions have been for what I honestly believed to be the truth, and when I have been shown to be, or found that I was, mistaken I have never hesitated to publicly acknowledge it. I have never taken difference of opinion as any cause for personal ill will, nor have I ever seen any reason why parties thus differing should not be the best of friends.

I gave the name Zirkelite to show my respect and esteem for the honored name of Zirkel, and to prove that, on my part at least, there was nothing except the kindest of feelings towards him. Everyone who has worked in the field to any extent amongst the older basaltic rocks, ought to know that specimens of Zirkelite can be collected by the thousands, and that the rock is no more "indefinitely decomposed and ill defined" than are the great majority of the rocks designated by specific names, and that it is more common than many of them.

If my fellow-workers will give the name decent treatment, the rock will perpetuate the great name of Zirkel when his work and that of all of us shall have been nearly or quite forgotten in the bright light of future progress. I ask you, as gentlemen, to give my absolute and unqualified denial of the truth of your associate's statement just as wide and public a circulation as you have given to his outrageous and unjustifiable libel.

Very respectfully yours,

M. E. Wadsworth.

Michigan College of Mines,
Houghton, Mich., June 14, 1897.

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An error was introduced in the scale of the map facing p. 250 of the last number of this Journal in the photographic reduction for which the author was not at all responsible. The scale should have read: Horizontal, 1 inch = 3 miles. Vertical, 1 inch = 3000 feet.

Reviews.

VAN HISE'S "PRINCIPLES OF PRE-CAMBRIAN GEOLOGY."

For some years investigators and teachers of dynamic geology have needed a revision of the theories of Dana, Fisher, Reade, Dutton, Kelvin, and others, with reference to rock deformation. The publications of Van Hise are a contribution to such a revision, and other articles in preparation by him may probably summarize existing knowledge and current theory in a form, which will be a material advance.

By training, experience, and bent of mind, Van Hise is fitted for the task. As assistant and successor to Irving in the geologic investigation of the Lake Superior iron region, he has solved the most difficult problems of the older rocks. In microscopic petrography of the crystalline schists and allied formations he is a leading authority. In obscure stratigraphy and complex structural relations he has had much experience. His base of observation has been broadened to include all important districts from the Pacific to the Atlantic, and the classic localities of Europe.

The *Principles of Pre-Cambrian Geology* is a work intended "(1) to give a partial discussion of principles applicable to geological work among the pre-Cambrian rocks of North America, and (2) to give an historical account of the North American pre-Cambrian, and to point out the principles illustrated in the various regions."

In Part I the author discusses (1) movements of rock materials under deformation, (2) analysis of folds, (3) cleavage and fissility, (4) joints, (5) faults, (6) autoclastic rocks, (7) metamorphism of the sedimentary rocks, (8) metamorphism of the igneous rocks, (9) phenomena of stratigraphy.

Part II describes the facts of historical geology in general for the Archæan and Algonkian periods, and in particular for ten districts of the United States and Canada in which rocks of these ages occur. There is an appendix on " Flow and Fracture of Rocks as Related to

Structure," by Leander Miller Hoskins, who treats the subject by mathematical analysis.

In 1878 Heim published his discussion of "Umformung durch Bruch and Umformung ohne Bruch."[1] It was necessary less than twenty years ago that he should present an elaborate argument to show that without the action of any softening agent rocks might be deformed without fracture under appropriate mechanical conditions. He had seen and understood qualitatively the facts of folded strata. Van Hise carries the interpretation to quantitative expression in terms of pressure per square inch dependent on depth beneath the earth's surface. Following Heim, and going further than he did, Van Hise formulates three principles:

(1) Rocks under less weight than their ultimate strength when rapidly deformed are in the zone of fracture. (2) Since the boundary between the zone of fracture and the zone of flowage is at a different depth for two rocks of unequal strength, and for the same rock under different conditions of stress, there is a zone of combined fracture and flowage. (3) Rocks buried to such depth that the weight of the superincumbent strata exceeds their ultimate strength are in the zone of plasticity and flowage.

Under the assumption that rocks are porous, and that, therefore, interstitial spaces at a depth are sustained by a column of water extending to the surface, the author calculates, from formulas furnished by Hoskins, that no cavity can exist permanently in even the strongest rock at depths of 10,000 meters or more below the surface. As the development of cavities is a feature of fracturing, deformation with fracture is not possible below that depth. That zone in which deformation occurs without fracture is designated by Van Hise the zone of flowage.[2]

Since rocks vary in strength the depth of the zone of flowage beneath the surface is variable, and where rocks of unequal strengths are interbedded the harder may be in the zone of fracture, the softer in the zone of flowage. It follows that there is a broad zone of fracture

[1] Mechanismus der Gebirgsbildung, Vol. II, pp. 3–75.

[2] Since the paper reviewed was written, Van Hise has described much more fully the minute phenomena of the zone of flowage (Bull. G. S. A., Vol. IX, pp. 295–312). According to his recent conclusions, the deformation in this zone includes both microscopical granulation of the mineral particles and their recrystallization. Therefore in this zone he recognizes microscopic fractures and openings.

and flowage intermediate between an upper zone, in which all rocks fracture, and a lower zone in which all flow.

Gilbert and Dutton, as well as Heim, had anticipated the conclusions of Van Hise in the general recognition of a zone of fracture and a zone of flow, but Van Hise first describes clearly the phenomena of a zone of combined fracture and flow, with which geological observation of structure has chiefly to deal. He contributes also a closer analysis of the phenomena in the uppermost and lower zones. The development of autoclastic breccias, the production of folds by opening of radial joints due to fracture, the association of deformation by fracture and without fracture in the same zone, the adjustments of form by which strata yield to folding, the disappearance of folds in depth, and finally the phenomena in the zone of flowage, are clearly and critically discussed.

The analysis of folds is based upon a classification by de Margerie and Heim, published in 1888, but their ideas are amplified, and a comprehensive classification capable of including all types is developed by the author's recognition of the complex nature of folds. The author's primary classification divides flexures into simple, composite, and complex folds. Simple folds are single anticlines and synclines, which are subclassified in the usual manner as upright, overturned, or recumbent, and as symmetrical or unsymmetrical folds. But Van Hise recognizes that every fold of any magnitude is complicated by minor folds and each of these again by still smaller folds, and so on to microscopic plications of the *n*th order. When thus considered, the major fold may be termed composite. Composite folds of the first magnitude were described by Dana as geosynclines and geoanticlines, and these, as Van Hise points out, are due to combined action of gravity and lateral thrust. In the discussion of composite folds they are classified as normal and abnormal, and the basis of classification is the direction of convergence or divergence of the axial planes of the secondary folds. Thus in a normal anticlinorium the axial planes of the secondary folds converge downward and diverge upward, whereas in an abnormal anticlinorium the axial planes of the secondary folds converge upward and diverge downward. No exception can be taken to this classification as a matter of fact, but as a scheme adapted to instruction or to practical discussion it may not be generally useful, because the mind is speedily confused by the repetition of the terms of upward and downward convergence as applied to anticlinoria and synclinoria of the various normal and abnormal types. Even one tolerably familiar with the aspects of folds must stop to draw a diagram before he can remember what the definition of a given type is.[1]

A definition of normal and abnormal folds, which may appear simpler, may be based on relative dips and depths of folds. It depends upon a law stated by Heim,[2] which is that from a normal anticline a stratum dips more steeply toward that syncline into which it descends to the greater depth. Thereon we may phrase the definition:

A normal fold is one in which the steeper dip is toward the deeper syncline of the same order, whereas an abnormal fold is one in which the steeper dip is toward the shallower syncline of the same order.

This definition has one advantage over that stated by Van Hise. It is related to the initial conditions which determine the positions of folds and their normal or abnormal development, whereas the axial planes are mathematical conceptions only, without actual existence. The relative depths of synclines and the steeper dips are frequently determined in the initial stages of development of folds, and persist as controlling conditions. In any littoral zone the steeper initial dip is usually from the land toward the sea. The resulting steeper dip after deformation holds a corresponding relation.[3]

Van Hise introduces a new use of the common term "monoclinal," in that he applies it to describe "that structure of a mountain mass in which the axial planes of all folds are inclined in the same direction." Discussing "monoclinal structure" he discriminates between overthrust folds and underthrust folds as follows, page 621:

"In monoclinal structure the force, and consequently the movement of the strata have usually been supposed to be more largely from one direction than from the other, and the axial planes of the folds have usually been regarded as dipping toward the force."

After reference to the ideas of H. D. Rogers, Van Hise continues, page 622:

[1] It has been suggested to me by Mr. L. C. Glenn that a general expression of Van Hise's law of normal folds may be phrased as follows: In a normal fold the axial planes converge centrically with reference to the arc which corresponds to the curvature of the anticlinorium or synclinorium. In an abnormal fold the axial planes converge eccentrically.

[2] Op. cit., pp. 231–233.

[3] Conditions of Appalachian Faulting, WILLIS and HAYES, Am. Jour. Sci., Vol. XLVI, October 1893.

"Folds thus produced by upward differential movement may be called 'overthrust folds.' The axial planes dip toward the effective stress, hence *overthrust folds are those in which the axial planes dip toward the force producing them.* While the development of overthrust folds is the general law, it may not infrequently happen that under favorable conditions the beds or formations may be thrust forward and downward. The folds thus produced by downward differential movement may be called 'underthrust folds.' The axial planes dip away from the effective stress, hence *underthrust folds are those in which the axial planes dip away from the force producing them.*"

The idea of Rogers that deformation proceeded by a wavelike motion, which, in the case of the Appalachians, emanated from the Atlantic region, is firmly fixed in geology without being sufficiently justified by facts. Appalachian structure in many districts presents a monoclinal inclination toward the southeast. If it be overthrust, the effective force operated from that direction. If it be underthrust, the effective force acted from the northwest. There is nothing in the monoclinal relations of folds which will determine that alternative. Theoretically, the geologist is at liberty to infer overthrust in preference to underthrust or *vice versa*, but an hypothesis of the origin of force based upon that inference is of no value. The analysis given by Van Hise leads him to the conclusion that the monoclinal folds and cleavage which prevail in the crystalline areas of the Appalachians are due to an effective force from the southeast, but that conclusion cannot be considered as demonstrated. Indeed, other geologists approaching the problem from a different point of view are justified in reaching the reversed conclusion.

It may be suggested that compression, which causes strata to fold, is a force of gradual accumulation, that is, of such slow growth that the pressure is transmitted through a rock-mass of indefinite extent until movement ensues. Such movement may probably begin at a point determined by local conditions, and may continue in a direction determined by the least resistance either as an overthrust or an under-thrust. In that view the more effective force is simply that which is opposed to the less effective resistance, and the hypothesis of a wave-like influence emanating from a distant source is unnecessary.

Complex folds are defined by Van Hise as those canoes, basins, and domes which result where two sets of folds intersect each other.

The two sets of folds may be produced simultaneously or at distinct epochs by two or more thrusts in diagonal directions or at right angles. Any two diverse thrusts inclined to each other may be resolved into two forces at right angles, which will produce complex folds; if, however, the divergence of the two thrusts is moderate, their effect may be combined to produce a simple system of parallel folds.

Of the two thrusts producing complex folds, one is usually the major thrust, the other the minor thrust, and the system of composite folds to which one or the other gives rise may be described accordingly as the major or the minor system. The length of canoes is proportioned to the difference in power between the major and minor thrusts. If the major thrust greatly exceeds the minor, the complex folds will be long, narrow, and parallel; if the two thrusts are nearly equal the folds will be domes and basins.

As an example of complex folds Van Hise refers to the Appalachian region. The reference, perhaps, requires qualification to modify its general application to the whole province. Districts of New England and North Carolina do exhibit complex folds which are markedly developed in the direction of the minor as well as of the major thrust, but in the Appalachian Valley region from New York to Alabama the folding scarcely appears to be complex. Van Hise cites the undulatory pitch of the axes as evidence of a pressure from northeast to southwest. The pitch is to some degree due to variations of initial dip and the depression of synclines in folding. There is no crenulation of the major strikes such as might be expected to result from a transverse thrust. If this zone of typical Appalachian structure shall be shown to be complex in the sense in which Van Hise defines the term, there will be good reason to assume that complex folding is the general rule. This may probably be so.

Van Hise's extensive experience in the study of complex structure enables him to suggest practical methods as to the manner of determining whether the rocks of the district are complexly folded and in what manner. These suggestions relate to the manner of making certain necessary observations, which he sums up as follows:

1. "Determine the strike and dip of the strata at the given point. These give the resultant position of the strata as tilted by the force of folding in both directions."

2. "Determine the direction of the pitch of the axes of the major folds. The first is the direction of dip, and the second is the amount

of dip of the minor or cross folds. The average strike is therefore determined."

3. "Determine the direction and pitch of the axes of the minor folds. The first is the direction of dip, and the second the amount of dip of the major folds. The average strike is therefore also determined."

Van Hise correctly observes that of these three observations the first is the only one ordinarily taken, and it is the one of least importance in regions of close complex folding. It becomes obvious in considering his practical suggestions that a thorough knowledge of the physiography of the region and the relation of relief to structure is quite as important for the solution of complex folds as is a knowledge of the rocks.

Concluding the section relating to folding, Van Hise considers the value of differential folding as an evidence of unconformity, when not sustained by other phenomena. A discordance in the flexures of two adjacent formations is only to be absolutely relied upon as evidence of unconformity when the structural discordance is so marked that the earlier series exhibits a relatively complex structure as compared with that of the later series.

In Section III Van Hise considers cleavage. He grasps hypotheses of the origin of cleavage advanced by other geologists from Phillips to Becker, discriminates between them, amplifies their basis of fact by his own extensive observations of the crystalline schists, and states those conclusions which he finds valid. He defines *cleavage* in a strict sense "as a capacity present in some rocks to break in certain directions more easily than in others." This use of the term is that in which it is applied to minerals. He distinguishes fissility as a phenomenon secondary to cleavage, fissility being "a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature."

Citing microscopical study of cleavable slates and schists, Van Hise concludes (page 635) that:

"Rock cleavage is due to the arrangement of the mineral particles with their longer diameters or readiest cleavage, or both, in a common direction, and that this arrangement is caused, first, and most important, by parallel development of new minerals; second, by the flattening and parallel rotation of old and new mineral particles; and third, and of least importance, by the rotation into approximately parallel positions of random original particles."

From these observations follows the inference that cleavage develops in a plane normal to the pressure. The grounds for this inference are discussed at some length and the author's opinion is finally stated (page 639):

"I therefore conclude from analysis, from experiments upon viscous and plastic bodies, from observations in the field, and from studies with the microscope, that I am justified in the statement that the secondary structure of a rock which is deformed by plastic flow develops in the plane normal to the greatest pressure, and that this structure is true cleavage."

From the observed parallelism to the inferred normal relation to pressure is a step in hypothesis. To this extent the conclusion falls short of demonstration, but it is in accord with the opinions of eminent students on cleavage, and is supported by mathematical analysts, with one marked exception. The exception is Mr. Geo. F. Becker.

It has been maintained by Becker that cleavage always develops in two shearing planes at angles to the pressure. His method of arriving at this conclusion may best be indicated by a quotation from his article:[1]

"In the following pages the attempt will be made to develop all the manifestations of uniform or homogeneous finite strain in rock-masses regarded as isotropic, exhibiting viscosity and capable of flow, which can be elucidated without assuming a law connecting stress and strain. For this purpose finite strain must first be discussed by itself; then it must be considered just how far the relations of stresses are capable of coördination with those of strain. The influence of viscosity and solid flow must next be shown. Readers willing to assume that these subjects have been logically treated will probably skip them and proceed to the geological applications which follow. Finally, the results will be compared with actually observed phenomena and with the experiments which several investigators have made on slaty structure."

The method followed by Van Hise is that of induction from the facts, whereas Becker pursues that of deduction from general principles. Van Hise does not deny the validity of Becker's reasoning nor its general application. He describes the development of fissility and jointing in the zone of fracture as in accordance with Becker's view. But he con-

[1] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by G. F. BECKER, Geol. Soc. Am., Vol. LV, 1891, p. 16.

cludes that in the zone of flow another process is effective to product cleavage; namely, special orientation of minerals and particles.

Fissility is defined by Van Hise as a parting of a rock along shearing planes, which corresponds with the structure described by Becker as cleavage. It is obvious that a capacity to part in a certain plane (Van Hise's cleavage) may often coincide with an actual parting developed later. If the capacity to part be a structure developed in the deep zone of flow, it is most probable that the actual parting should be developed in rising through the zone of fracture, as any rock mass must to become accessible to our observation. Hence arises the opportunity for confusion of the two structures, according to Van Hise, but discriminating the one from the other he concludes that: "Fissility developing in the shearing planes is usually secondary to cleavage which developed in the normal planes."

The relations of cleavage and fissility to bedding and to folds are discussed at length, and the value of these structures as criteria for determining unconformities are stated and limited.

With reference to joints Van Hise's discussion is along lines logically consistent with his views of folding and also of fissility. Tension joints may be produced radially to the curvature of folds; this phenomenon he rightly considers important as a means of accommodation to curvature in the zone of fracture. Compression joints develop in shearing planes, usually in two directions, and when associated with simple folds generally parallel to the strike. When folding is complex different sets of shearing plains may correspond to strike-joints and dip-joints, but the association of three or more joint systems may probably be the result of several orogenic movements.

Faults also are classified as tension faults and compression faults, but recognizing the dominant influence of gravity or of thrust respectively, Van Hise well prefers to distinguish them as "gravity" faults and "thrust" faults. The former is equivalent to the old term "normal," the latter to the inaccurate designation "reversed" fault.

In discussing the relation of faults to folds it is stated that under moderate load thrust faults may result as clean cut fractures, whereas under greater load they may be associated with overfolds, and at still greater depths overfolds may develop without thrust faults.

"This statement might be well supplemented by the further explanation that folds may give place to thrusts on diagonal planes in the deep zone of flowage. Two conditions are essential to folding;

first, that the stratum shall be sufficiently rigid to transmit a maximum stress in a definite direction; and second, that movement on bedding planes shall afford a means to adjustment to curvature. It is an open question how far these conditions are effective in a deep zone of flow. In the opinion of the reviewer neither of them exercises a dominant influence. Distinctions of stratification may become insignificant under excessive pressure, and great friction on bedding planes may prevent accommodation, and the mass may be deformed by dislocation in the diagonal planes. This is illustrated in model J, Plate XCIII, stages *f* to *k*, "Mechanics of Appalachian Structure." The accommodation of the soft material to shortening in one direction and elongation in another is there accomplished by the reciprocal displacement of wedges, which are defined by planes diagonal to the applied force. This explanation is briefly suggested by Van Hise in a subsequent paragraph on the depth of the zone affected by faults, but he fails to emphasize the idea that while thrusts developed in the zone of fracture pass into folds below, folds in turn may be replaced by thrusts at still greater depths. The relation is important."

Comparing the effect of few great structures with that of numerous small ones, Van Hise concludes:

"The average deformation of a region may be the same whether it be by a few great faults with little or no fissility, by more frequent lesser faults with or without fissility, by faults and overfolds with or without both cleavage and fissility, or by folding with or without faults and cleavage; also that there is every gradation between faulting and fissility, and probably every gradation between faulting and cleavage."

In Section VI, Van Hise discusses dynamic breccias and pseudo conglomerates under the generic term of "autoclastic" rocks, which was first used by H. L. Smyth. The development of autoclastic rocks is limited to the zone of fracture and they are not of common occurrence in strata younger than the Cambrian. But where they occur in rocks which have undergone repeated disturbances the resulting dynamic breccia may so resemble a basal conglomerate as to lead to an erroneous inference of unconformity. In the discussion of these cases Van Hise inadvertently illustrates with what remarkable care and patience the geologic study of the Marquette district has been pursued.

Metamorphism is treated in sections VII and VIII, with the purpose "briefly to sketch a few of the more important processes which have affected large areas of the pre-Cambrian rocks of North America." The author recognizes pressure, heat and chemical affinity as the prominent forces producing metamorphism. When pressure is resisted by rigidity, *i. e.*, produces only molecular motion, the result is static metamorphism; when pressure passes into mass motion the result is dynamic metamorphism. The chief processes considered are consolidation, welding, cementation, injection, metasomatism, and mashing.

In discussing cementation and injection the author takes up the origin of pegmatites and says:

"It seems to me that to adequately explain all the facts of pegmatization described in various regions of the world, we must conclude that all three processes have been at work—in some cases igneous injection, in some cases aqueo-igneous action, and in other cases pure-water cementation, and in still others combinations of two or all of these processes. It is further believed that there may be no sharp separation, but, on the contrary, all gradations between the three—that is, it is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. In other words, under proper conditions water and liquid rock are miscible in all proportions. From the water solutions true impregnation or cementation would take place; from the rock solutions, true injection. Pegmatization may comprise these and the intermediate processes."

Metasomatism is described with reference to (1) "alteration of original mineral particles, (2) minerals produced by alterations, and (3) texture of rocks produced." The brief statement of facts familiar to petrographers suggests also brcader aspects of comparative petrology.

"Mashing is a term here introduced with a specific meaning. It is used to designate by a single word that complex process which involves shortening without change of volume, or simple shearing, or a combination of the two. Mashing implies all the other special processes of metamorphism."

Having thus considered in general the processes of metamorphism, Van Hise classifies metamorphic sedimentary rocks according to those processes which have been particularly effective in the development of each class. The enumeration of rock types in relation to conditions affecting their development is particularly valuable.

Metamorphic igneous rocks are treated separately, though briefly, but the means of discriminating between originally sedimentary and originally igneous rocks are discussed with the insight due to broad observation. The difficulties of discrimination are suggested in the following statement:

"It has been seen on previous pages that a large number of kinds of schists and gneisses may be produced by the metamorphism of sedimentary rocks; also it has been shown that similar crystalline schists may be derived from igneous rocks. It is further certain that a schist or gneiss may be derived partly from sedimentary and partly from igneous rocks. For instance, a metamorphosed fissile sedimentary rock, such as mica-schist or mica-gneiss, may be injected in a complicated way parallel to the planes of schistosity, and thus produce a banded gneiss, part of which is igneous and part of which is sedimentary. The rock may be predominantly of either one of these materials. If the injected sedimentary rock be subsequently folded, this will produce differential movements parallel to the banding, and the igneous and aqueous bands may be merged into one another and have structures so similar that it is impossible to determine what part of the rock is igneous and what part aqueous. The Manhattan schists of southeastern New York, and especially near Long Island Sound, are a perfect illustration of a gneiss produced by the extreme metamorphism of a sedimentary schist and the subsequent parallel and cross injection of granitic material.

"From the foregoing it is clear that an inseparable schist or gneiss formation may be produced from altered intrusive rocks, from altered lavas, from altered tuffs, from altered sediments, and from any possible combination of two or more of these.

"Doubtless, in regions in which the gneisses are of a very complex character, a number of the processes mentioned in the previous pages, and possibly others unknown, must be united in order to explain all of the phenomena."

Stratigraphy, *i. e.*, the sequence of formations, is deduced for pre-Cambrian rocks from observations of the phenomena of structure and metamorphism and other relations in detail. It thus becomes an inference instead of being a primary fact of observation, as it may be in rocks which are less disturbed. Van Hise, therefore, gives stratigraphy a logical position at the close of his discussion of principles. The evidences of stratification which are obvious in unaltered series may be so obscured in older rocks as to be determinable only by the closest observation. Hence, bedding, ripple marks, basal conglomerates, and phenomena indicating unconformity afford material for extended consideration.

This review would be made too long by detailed references to the second part of the "Principles," which treats of the historical geology of the pre-Cambrian time. The discussion is arranged according to districts and for each district the principle most saliently illustrated is emphasized. This part of the book constitutes a valuable summary of existing knowledge and a convenient and reliable reference.

The style of the author is the expression of complete knowledge of his subject, combined with exuberance of thought. Another great writer, whose works are characterized by brilliancy and clearness, recently said: "When I undertake to write a book I endeavor first to see what I can exclude from it, and after the process of rigid exclusion I carefully arrange the surviving ideas even to the order of paragraphs before I write." The thoughts which rush upon Van Hise are related in so many directions that many associations of the idea seek expression at once. His book would be easier to read and not necessarily less accurate, if the thought were stripped. The logical analysis is consistently carried out for all the major headings, but it is not adequately extended to the paragraphs and sentences. Nevertheless, a thorough study of the work leaves a profound impression of the earnest purpose with which it has been conceived and of its value as a contribution to one of the most difficult branches of geologic science.

BAILEY WILLIS.

Topographic Atlas of the United States. Physiographic Types by HENRY GANNETT. Washington: U. S. Geological Survey, 1898.

The enlightened policy adopted by our national Geological Survey of encouraging as wide a use as possible of the material gathered at great expense receives a new and welcome illustration in the publication of the first folio of the above named series. It presents ten maps as "illustrations of some of the simplest and most characteristic types of topography to be found in those parts of the United States which have been thus far mapped. Succeeding folios will illustrate more complex forms." The origin of the atlas was in a proposition of the director of the survey to publish "an educational series of folios, for use wherever geography is taught in high schools, academies and colleges," authority for such publication having been granted by Congress in an act approved March 2, 1895.

The following titles represent the contents of this first folio: A region in youth: Fargo, North Dakota-Minnesota. A region in maturity: Charleston, W. Va. A region in old age: Caldwell, Kan. A rejuvenated region: Palmyra, Va. A young volcanic mountain: Mt. Shasta, Cal. Moraines: Eagle, Wis. Drumlins: Sun Prairie, Wis. River Flood Plains: Donaldsonville, La. A fiord coast: Boothbay, Me. A barrier-beach coast: Atlantic City, N. J. It may well be claimed that no more important, useful, or interesting series of maps could be selected for the elementary exposition of physiographic types.

It must be most encouraging to teachers of geography to find so efficient an ally as this series of folios will prove. Such a publication gives an authoritative stamp, such as has not yet been received in any other country, to the methods of modern physiographic description. It recognizes the essential importance of stage of dissection and movement with respect to baselevel, as a means, not merely of explaining the past history of a region, but of describing its present form. Withal, the text is written in a clear and simple style, certainly within the reach of even those teachers of other subjects upon whom the unexpected responsibility of having to teach geography so often falls. The few technical terms that are employed are fully explained. The relation of form to conditions of settlement and movement are touched upon. The later numbers of the series will be awaited with much interest.

Where so much is good, it gives regret to find the text of one map open to adverse criticism. The account of the Booth Bay sheet needs revision regarding glacial action. The region is described as having been for a long time "subjected to aqueous erosion, which brought it to a condition of old age with gently flowing streams, smooth slopes, and rounded divides." Upon such a surface advanced the Great Northern Glacier, and proceeded to modify it. It is difficult for the reader of this part of the text to avoid concluding that when southern Maine was thus "planed down by aqueous erosion," it was about as flat as the plains of Kansas—the type of old age—and that its marked relief today is the result of glacial erosion. There is, on the contrary, good reason for believing that since the greater part of New England was brought to a condition of old age, it has been rejuvenated and more maturely dissected than the Piedmont upland of Virginia, the type of renewed dissection in a second cycle. The ice-sheet therefore advanced over a region of distinct hills and valleys, not over a peneplain. The implication that the ice-sheet was an effective agent of destruction is confirmed on reading that the traces of glacial action "here consist mainly of features of erosion. But little matter was deposited by it, that little consisting of what is known as 'erratics,' or granite bowlders, which are scattered freely over the country. . . . . A great deal of erosion, however, was done by the ice-sheet. It searched out very keenly the soft spots in the granite surface of the country and scoured them away, leaving depressions and, between such depressions, rounded hills of granite. . . . . All of the soil or disintegrated rock was scraped away, leaving the granite bare; hence it is that the soil covering of southern Maine is very thin, for it has been derived mainly from the disintegration of rocks since the passing of the glacier." Apart from the implication that the hills today result from the glacial excavation of depressions between them, and from the implication that granite is the only kind of rock in this region whose linear ridges and fiords give so strong an indication of foliated or stratified structures, it is unfortunate that the common veneer of till, the relatively plentiful deposits of washed gravel and sand, and the important cover of marine clays in the valley floors of southern Maine should pass unnoticed. The farmers of that region very rarely depend on soil of postglacial weathering. The rocky ridges with a thin soil, partly of glacial drift, partly of postglacial weathering, are left in uncultivated forests and woodlots.

It is further to be regretted that, after showing by the first four types that time is an important element in geographical description, no sufficient mention is made of the element of time in connection with the two examples of shore-line features. It is of course recognized that the irregular coast line of Maine is a result of the partial submergence of a rugged land; but no consideration is given to the evidence that the submergence is recent; so recent that wave action has not yet cut back the headlands, and that river action has not yet filled up the bay heads. Hence the account of shore lines is not homologous with that of land surfaces, in which the stage of advance reached by destructive processes is carefully considered. The opportunity for teaching an important principle in the evolution of shore lines is thus lost.

W. M. Davis.

Volcanoes of North America : A reading lesson for students of Geography and Geology. By ISRAEL C. RUSSELL. The Macmillan Company, New York, 1897.

The object of this book is plainly stated by the author in the introduction—"It is to the character and history of this vast volcanic belt, reaching from the tropical shores of Costa Rica to the western extremity of the bleak and inhospitable Aleutian Islands, that the attention of students of geology and geography is here invited. The object of this book is to make clear the principal features of volcanoes in general, and to place in the hands of students a concise account of its leading facts thus far discovered concerning the physical features of North America which can be traced directly to the influence of volcanic action." Its title indicates that it is not intended to be a thorough treatise on the subject, but rather a readable account of the leading features. It will undoubtedly prove satisfactory to those who read it with this understanding. It has gathered together in an attractive form many scattered descriptions of the volcanoes and volcanic mountains of North America, and has placed the student in the way of finding the original accounts. It will excite interest in the volcanic phenomena to be found on this continent and will perform a helpful mission. The arrangement of the material is good and the interest of the reader well sustained by the general style. The illustrations are valuable and attractive.

There are, however, numerous evidences of carelessness in the work which are to be regretted. The section on the Characteristics of Igneous Rocks is open to severe criticism. Its definitions are crude and misleading, and incorrect arguments are presented in several instances. The section should be carefully revised.

The effort to connect the active volcanoes of Central America with those of the Aleutian islands, as though they constituted one chain, is not justified by the facts; the former being much more closely connected with those of the Andes, and the Alaskan volcanoes with those of the Japanese islands.

The descriptions of the volcanoes within the United States are somewhat unsatisfactory since they bear little relation to their relative importance. Considerable space is devoted to detailed descriptions of very insignificant craters in Utah and Nevada, and to the comparatively small volcanoes near Mono Lake, Nev., while much less is given to that of the great mountains, Shasta, Rainier, and other volcanoes of the Pacific Coast. And no mention whatever is made of the volcanic region of the Yellowstone National Park, a region not only characterized by great diversity of volcanic phenomena, where the influence of volcanic action on the physical features of the region is most marked, but one that is being constantly visited by students and tourists.

The chapter devoted to the theories of volcanic action is good in the main for an elementary treatment of the subject. But some of the reasoning is obscure, especially that with reference to the behavior of absorbed vapors, and the question of their presence or absence from deep-seated and surface rocks. The effort to minimize the effect of steam upon the eruption of lava appears to have been carried too far.

It is greatly to be regretted that defects such as these exist in a book that has so many excellent features to recommend it.

J. P. I.

Revised Text-Book of Geology. By JAMES D. DANA. Edited by WILLIAM NORTH RICE. American Book Company, New York.

The earlier editions of this work are so well known that interest in the present edition is concerned chiefly with the nature of the revision. This had been begun by Professor Dana a short time before his death, but little progress had been made. By request, his former pupil, Dr. William North Rice, completed the work. His aim has been to retain the distinctive characteristics of the book so far as possible and, while bringing it down to the present time as regards its facts, to preserve the known opinions of its author. The editor has endeavored to subordinate his own views to those of the original author, although on certain points, as for example, geographic and climatic oscillations of the Quaternary era, he would have preferred a somewhat different expression. The general plan of arrangement remains unchanged and the omissions about counterbalance the introductions. The zoölogical and botanical classifications previously used were judged to be obsolete and the schemes followed in a majority of the recent manuals of zoölogy and botany were substituted. The theory of evolution finds fuller recognition than in the previous editions. In the treatment of metamorphism the text is considerably modified, especially with reference to the dynamic phases and to the foliated structure of igneous rocks. Otherwise the book presents essentially the views of science held by the distinguished author in his later years. In the very delicate task of eliminating such errors as the progress of science has developed, and at the same time of deferring almost reverentially to the opinion of the author, Dr. Rice appears to have attained a high degree of success, although some further eliminations of opinions and interpretations which, though not absolutely abandoned by all geologists, have been practically overthrown, might have added value to the work. T. C. C.

Fossil Plants for Students of Botany and Geology, Vol. I, 450 pp., with illustrations. By A. C. SEWARD, University Press, Cambridge, Eng., 1898.

Botanists and geologists both are bound to welcome Professor Seward's work on Fossil Plants, the first volume of which has recently appeared. This book forms one of the familiar Cambridge Natural Science Manuals, and is rather more extensive than the others. It is safe to say that no general work on palæobotany had previously appeared in English that was satisfactory to both botanists and geologists, and very few that were satisfactory to either. Hence it is a pleasure to read in the preface that this book is intended for both botanists and geologists, and thus has to be adapted to both non-geologists and non-botanists, since it is unfortunately true that neither class, as a rule, appreciates the standpoint of the other. The first chapter contains a brief historical sketch of palæobotany in which the author gives special credit to Brongniart and Williamson. Chapter ii gives the relation of the subject to botany and geology. Professor Seward tells how palæobotany has been buffeted about by the geologist and the botanist, the one culling out facts relating to correlation of strata, the other caring only for facts which give hints as to phylogeny and evolution. He pleads for the recognition of palæobotany as a science of and for itself, with its own peculiar problems, viz., the determination of the historical succession of plants in geological time; the delineation of the actual evolution of the plant kingdom, giving light on phylogenetic mysteries; the presentation of the various floral areas of the past, leading up to an explanation of the distribution of plants in the present day; conclusions as to climatic and other conditions in geological time as revealed by the occurrence of certain peculiar plant types and by anatomical adaptations to environment. The third chapter gives the leading facts of geological history, and is designed for botanical readers. The next chapter discusses the various methods for the preservation of plants as fossils; structure unmodified, as in fossil soils and forests; carbonization; incrustation, as travertine; casts; petrifactions. The relative rarity of plant fossils is due to their soft structure and land habitats. Chapter v is exceedingly interesting and valuable, as it demonstrates the enormous difficulties and sources of error, such as (1) the danger of depending too much on external resemblances, since many forms from algæ up to seed plants may look alike even in modern forms, much more in fossils; (2) fragmental preservation — this is much more common than in animal fossils, and also leads to much more error, since a plant often can be identified only in fruit; (3) decorticated trunk and pith cylinders; (4) resemblance to animals or animal tracks and mineral deposits.

After a chapter on nomenclature, the author takes up the plants by groups. In this first volume he treats only of the Thallophytes, Bryophytes, and some Pteridophytes. Among the algæ there is an abundance of undoubted fossil blue-green algæ, forming deposits of travertine and possibly oölite. Professor Seward thinks that similar forms probably represented the first life of the Algonkian. Because of their siliceous tests there are vast deposits of diatoms, mainly from the Cretaceous on. Of the larger marine algæ those forms are especially preserved which are covered during life by calcareous incrustations, especially the corallines. Many plants of all kinds and many mineral deposits, rill marks, and animal tracks have been referred to the algæ, and especially to the fucoids. Among fungi there are abundant evidences of fossil bacteria, but the higher forms are rare, though found in the Carboniferous and Tertiary. The liverworts and mosses are poorly preserved and difficult to identify. Of the Pteridophytes, the author considers in this volume only the equisetales and sphenophyllales. Both of these groups are abundantly preserved and well known. At the close of the volume is an excellent bibliography.

This work of Seward's has at least three features to commend it that are by no means common to all books on palæobotany. It is extremely cautious in its statements; many forms commonly described are either classified tentatively or omitted altogether. There are not so many startling allusions to high-grade plants in the early ages, but there are more real facts on which to base safe conclusions. Another valuable feature of the book is that important facts have been culled out from a mass of unimportant material; and by no means least in its commendable qualities is the fact that it is actually readable; even the botanical or geological layman may enjoy it if he cares for such things at all. Everyone who reads the first volume will anxiously await the appearance of the second.

HENRY C. COWLES.

Northward Over the "Great Ice": A Narrative of Life and Work along the Shores and upon the Interior Ice-Cap of Northern Greenland in the years 1886 and 1891–1897. By ROBERT E. PEARY. 2 vols. Illustrated. Frederick A. Stokes Co., New York. 1898.

In these two volumes, embracing nearly 1200 pages, Lieutenant Peary has given a graphic account of his entire Arctic work. The story begins with a reconnaissance of the inland ice of Greenland in 1886. The objects and results of this reconnaissance he summarizes as follows:

Objects. — To gain a practical knowledge of the obstacles and ice conditions of the interior of Greenland; to put to the test of actual use certain methods and details of equipment; to make such scientific observations as may be practicable; and to push into the interior as far as possible. (Paper read before National Academy of Sciences at Washington, D. C., April 23, 1886.)

Results. — Attainment of greater elevation tban ever before reached on the inland ice; penetration a greater distance than any white man previously; attainment for first time of the real interior plateau of unchanging snow; determination of ruling characteristics of the inland ice from border to interior (see article in *Bulletin Am. Geog. Soc.*, No. 3, 1887, pp. 286–288); securing an invaluable fund of definite practical knowledge and experience of actual ice-cap conditions and necessary equipment, as well as practical knowledge of Arctic navigation and a familiarity with a considerable extent of the Arctic coasts; inception of ideas of pronounced future value, as odometer, sails, etc. The following deductions: Attacks upon the inland ice should be made at a point as far above level of sea as possible, and where the presence of large and rapidly discharging glaciers indicates a rapid ascent to high elevations in close proximity to coast; party should be *small*, and thoroughly accustomed to snowshoes and ski; surface of inland ice offers imperial highway to east coast, and, in case the ice-cap is coëxtensive with the land, to the northern terminus of Greenland. Proposal of the following prophetic routes: From base of Noursoak Peninsula to head of Franz Joseph Fjord and return; from Whale Sound to northern terminus of Greenland or intersection of ice-cap with east coast — this route the key to the Greenland problem; from Disco Bay to Cape Dan.

The remainder of Vol. I is occupied by the story of the North Greenland expedition of 1891–2. Most of our readers are doubtless familiar with this famous trip across the northern portion of the great ice-cap, but still they will read this authoritative statement by the explorer himself with fresh interest and satisfaction. The author summarizes the objects and results of this expedition as follows:

Objects. — Determination of the northern limit of Greenland overland; the possible discovery of the most practicable route to the Pole; the study of the Whale Sound Eskimos; the securing of geographical and meteorological data.

Results. — The determination of the northern extension and the insularity of Greenland, and the delineation of the northern extension of the greater interior ice-cap; the discovery of detached ice-free land-masses of less extent to the northward; the determination of the rapid convergence of the Greenland shores above the seventy-eighth parallel; the observation of the relief of an exceptionally large area of the inland ice; the delineation of the unknown shores of Inglefield Gulf; and the imperfectly known shores of Whale and Murchison sounds; the discovery of a large number of glaciers of the first magnitude; the first complete and accurate recorded information of the peculiar and isolated tribe of Arctic Highlanders (Dr. Cook); complete and painstaking meteorologlcal and tidal observations (Verhoeff); sledge journey, which is unique in respect to the distance covered by two men without a cache from beginning to end, and in respect to the effectiveness with which those men were able to handle a large team of Eskimo dogs; corroboration of the opinion advanced that the inland ice offered an "imperial highway."

Vol. II opens with a narrative of the expedition of 1893–4, which is memorable on account of the great equinoctial storm encountered, that appears to have been without a recorded parallel even in that land of terrific gales, and that proved disastrous to the undertaking. Among the subsidiary narratives of special interest are the stories of the discovery of the great Cape York meteorite by Peary and the reconnaissance of Melville Bay by Astrup. In this part are also included a summary of the valuable meteorological observations of Baldwin. Then follows an account of the visitation of the *Falcon*, the return of the larger part of the party, the voyages of the fall and the winter, and the story of the third winter passed in the high north.

The climax of sympathetic interest is reached when Peary comes to tell of his second crossing of the ice-cap in the face of unusual difficulties, and of the scant margin by which he escaped several threatened sources of disaster. The objects and results of the expeditions of 1893–5 are summarized as follows:

Objects.—The delimitation of the detached lands lying north of main Greenland; the filling in of the remaining gaps in the northern and north-eastern coast line of Greenland; in the event of favorable conditions, an attempt upon the Pole; the completion of the detail survey of the Whale Sound region; continuation of the studies of the Smith Sound Eskimos; the discovery of the "Iron Mountain."

Results.—The crossing of the inland ice-cap of north Greenland under a most serious handicap of insufficient provisions; the completion of the detail survey of Whale Sound; large accessions of material and information in connection with the Smith Sound Eskimos; the discovery of the "Iron Mountain" or Cape York "Saviksue," and the bringing home of two of those interesting meteorites.

The work is completed by the narrative of the two summer voyages made in 1896 and 1897, whose chief object was the bringing home of the great Cape York meteorite, which was successfully accomplished by the latter expedition.

The work is written in clear and graphic style, and the story is followed with ease and satisfaction by the reader. The narrative moves forward at a steady and rather rapid pace, and is unusually free from tedious passages. The size of the work is not due to needless deployment of details or the introduction of much subjective matter. It is merely an expression of the great amount of work which Lieutenant Peary has done. His aim has been, as stated in the preface, to condense and to avoid all padding. In the main he has avoided exploiting his feelings, a practice quite too much the fashion with Arctic explorers. When he has given them expression it has usually been on occasions that specially invited it, and then with brevity and good taste.

The scientific reader will of course wish that the natural phenomena of that wonderful region had been set forth with greater detail and with more special reference to their scientific bearings, but this would doubtless have been less acceptable to the great mass of readers for whom the work was written. There is a hint that the scientific results will be specially treated in some later work. The scientist will, however, find this work rich in phenomena of the highest interest, not less in the illustrations than in the text. No work on the great white north has ever been so amply and so accurately illustrated as this. The 800 photographic illustrations tell their own story. Lieutenant Peary was as fortunate as he was industrious in making an unassailable photographic record of his explorations. Neither storms, dangers, nor stress of circumstances seem to have stopped the work of his ever-present kodak. The mechanical execution of the half-tones, while in the main fair, yet leaves something to be desired. Their extreme value would have warranted the use of the best available paper and of the utmost skill in printing. Their execution is sufficiently good, however, to lend an inestimable value and interest to the text.

T. C. C.

United States Geologic Atlas, Folio 41, Sonora, California. 1897.

The folio consists of seven pages of text signed by H. W. Turner and F. L. Ransome, geologists, a topographic map of the district, an historical geology sheet, an economic geology sheet, and a structure section sheet.

The quadrangle represented in this folio lies between the parallels of 37° 30′ and 38° north latitude, and meridians of 120° and 120° 30′ west longitude. It comprises a portion of the western slope of the central Sierra Nevada, chiefly in the foothill region. The quadrangle covers portions of Tuolumne and Mariposa counties, including, also, corners of the valley counties of Stanislaus and Merced. The area is drained chiefly by the Tuolumne and Merced rivers.

The formations are divided into two main groups: The bedrock series, and the superjacent series. The bedrock series is composed of Juratrias and Palæozoic sediments with interbedded lavas and tuffs, and a series of old igneous rocks, chiefly quartz-diorites, serpentine derived from peridotite, and porphyries. The Juratrias rocks are chiefly clay-slates with some sandstone, and are called the Mariposa formation, since the characteristic Jurassic fossils of the formation were first found in Mariposa county. The Mariposa formation is represented by three distinct belts of slates, the most eastern belt of which is remarkable as containing in part the gold-bearing veins of the mother lode. The Palæozoic sediments are called the Calaveras formation. The only evidence of the age of this formation in the limits of the quadrangle consists in rounded crinoid stems found in limestone on Mormon Creek, but the formation is stratigraphically continuous with the Calaveras formation of the Jackson and Yosemite quadrangles, in both of which Carboniferous fossils have been found. The pre-Cretaceous rocks in general are very similiar to those of other portions of the Gold Belt, but two rock types occur here that are rare elsewhere. These two types are certain soda-feldspar dike rocks, called soda-syenite, and a hornblende-pyroxene rock. The soda-feldspar dikes occur chiefly along the mother lode and at many points have been altered by mineral solutions which have deposited calcite, dolomite, pyrite and some gold and silver. East of Jacksonville, at Kanaka Creek, and east of Moccasin Creek, these dike rocks have been extensively exploited for gold. The soda-feldspar dikes (soda-syenite) of the Sonora quadrangle are practically the same as the soda-syenite which forms the lode of the Treadwell mine on Douglas Island in Alaska. The hornblende-pyroxene rock, above referred to, is chiefly remarkable as being apparently unique. The hornblende forms porphyritic crystals in a finer ground mass of augite and hornblende.

The superjacent series is composed of Eocene beds, Miocene beds, andesitic sandstone, auriferous gravels, and various lavas. All of the rocks of the bedrock series were greatly eroded during Cretaceous and early Tertiary time, and upon this old surface of erosion, or approximate peneplain, the river gravels and lavas of the superjacent series were deposited. During Cretaceous and a large portion of Tertiary time the San Joaquin Valley was under water. The sediments deposited at that time, which have been preserved in the Sonora quadrangle, consist of sandstone of Eocene age (Tejon formation), shale, sandstone, clay and rhyolitic tuff of supposed upper Miocene age (Ione formation), and coarse andesitic sandstones and conglomerates which are presumably of Pliocene age. The gravels deposited by the rivers of this period are called the Auriferous river gravels. These river deposits have very largely disappeared through erosion, but are still preserved at some points underneath the lavas of late Tertiary. The best preserved river channel is that underlying the Tuolumne Table Mountain west of Sonora. This mountain owes its table character to a dark basaltic rock (*latite*) which flowed down the valley of the Neocene

Tuolumne river. The low ridges that formed the sides of this Neocene river valley have since that time been worn away by the erosive agencies, leaving the river channel with its hard basaltic capping standing above the surrounding country. At many points tunnels have been run in under the lava capping to penetrate the gravels beds, which have proved highly auriferous at some points. Rhyolite lavas which are so abundant in the Sierra Nevada to the north of the Sonora quadrangle have been found here only in small amount intercalated in the beds of the Ione formation. The andesitic tuffs and breccias, which, at one time, must have covered a large portion of the northern half of the quadrangle, have largely disappeared. The Table Mountain basalt is evidently younger than a portion of the andesite, as it overlies andesitic tuffs and gravels.

Economic geology.—The Sonora quadrangle comprises a portion of the southern part of the mother lode gold district. This remarkable linear system of gold quartz veins extends across the quadrangle in a northwest-southeast direction, and lies partly within the eastern belt of the slates of the Mariposa formation and partly to the east of this belt. Many of the mines are now being operated with good results. Profitable gold quartz veins are also found in the bedrock series, both to the east and west of the mother lode district. The mines in the granodiorite east of Sonora have been worked with varying success for many years. The limestone of the Calaveras formation, which extends from Sonora to the southeast, has been largely metamorphosed into marble, much of which is valuable for building purposes. Chrome-iron deposits occur within the serpentine areas. The sandstones of the Ione and Tejon formations, along the borders of the great valley, are valuable for building stone. The forest zone of the northeastern portion of the quadrangle furnishes valuable timber for the mines and for building purposes.

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